SENTINEL 2

Mission Performance Centre

Telespazio
A Finmeccanica/Thales Compa

DLR

esa

European Commission

SENTINEL-2 L2A PROCESSOR SEN2COR

EUFAR ESA WORKSHOP ON ATMOSPHERIC CORRECTION OF

REMOTE SENSING DATA 26 – 28 OCTOBER 2016, BERLIN, GERMANY

CS ACRI ST ARGANS elecnor deimos gmv AIRBUS DEFENCE & SPACE ThalesAlenia Space IGN ONERA Telespazio A Finmeccanica/Thales Company DLR

SENTINEL-2 MPC CONTEXT

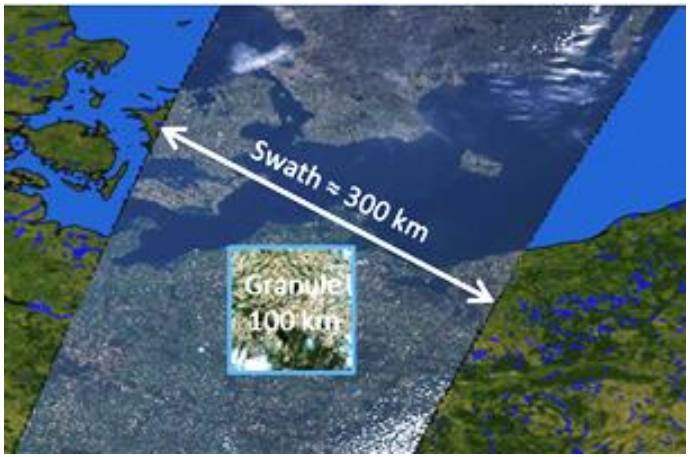
- Sentinel-2 Mission Performance Centre (MPC)
- MPC/CC in Sophia-Antipolis
- Expert Support Laboratories:
  - L1_CAL
  - L1_VAL
  - **L2A**

OUTLINE

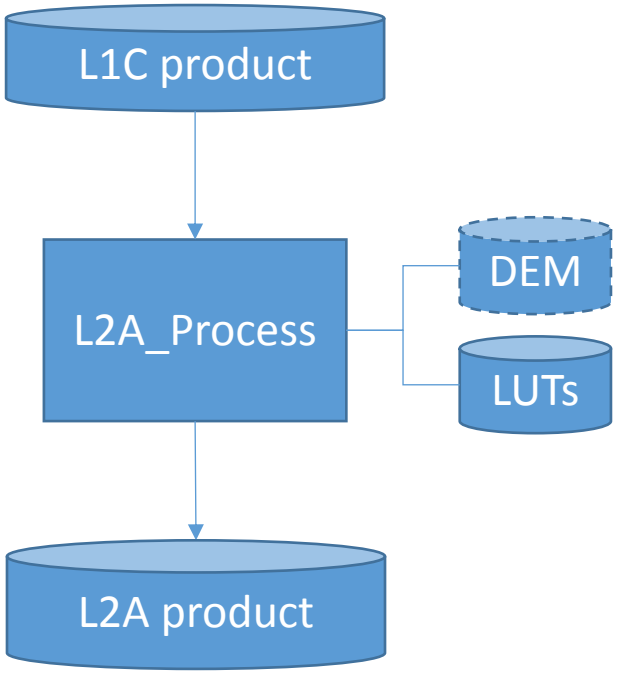
- Sen2Cor processor
- Processing examples
- Sen2Cor algorithms
- Validation

SEN2COR OVERVIEW

- Single-Mission tool for Sentinel-2 mission
- Atmospheric Correction over land surface
- Processing on orthorectified L1C granule for a single-time image

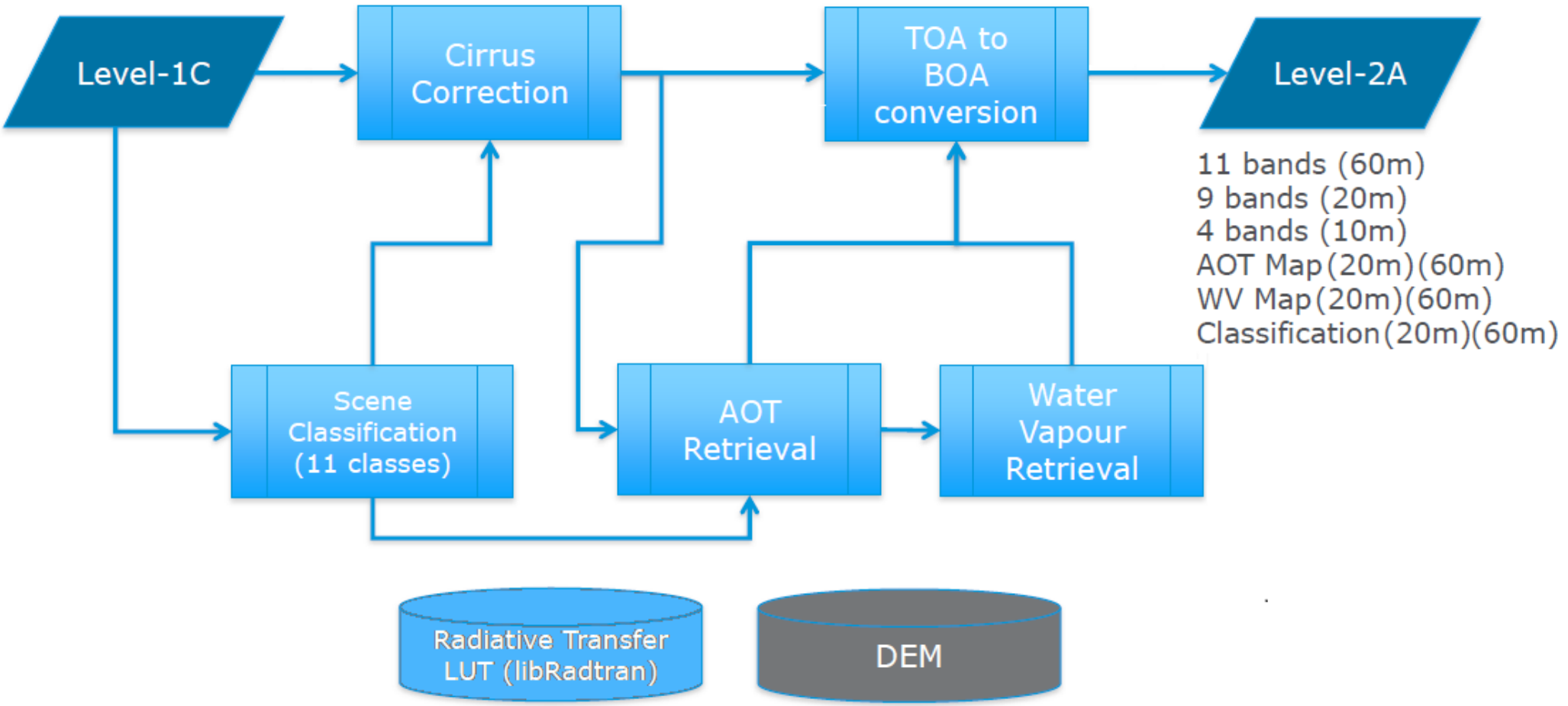


- Radiative Transfer code: LibRadtran (Look-Up-Tables)



- Python application, Command line tool, also available from S2 toolbox
  - Requires: Anaconda, GDAL, OpenJPEG
- Processing configuration: XML-file

SEN2COR: MAIN PROCESSING STEPS



Cirrus correction
B10 (1375 nm, 60m)

AOT-retrieval
B2 (490 nm, 10 m resampled)
B4 (665 nm, 10 m resampled)
B12 (2190 nm, 20 m)

WV-retrieval
B8A (865nm, 20 m resampled)
B9 (945nm, 60m)

Terrain correction
DEM

SEN2COR: PROCESSING CONFIGURATION (XML-FILE)

Ground Image Processing Parameter (GIPP):

- Cloud Screening and scene Classification GIPPs
- Atmospheric correction GIPPs

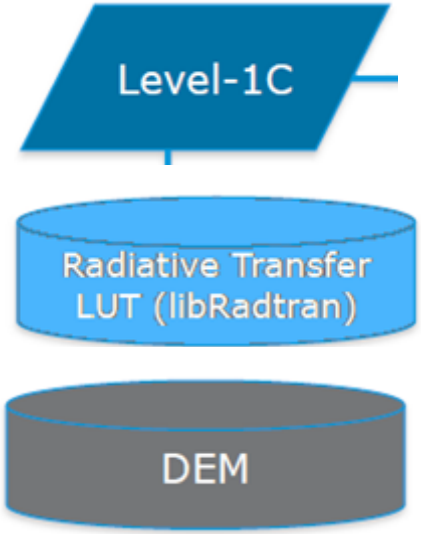
- User GIPPs: L2A_GIPP.xml

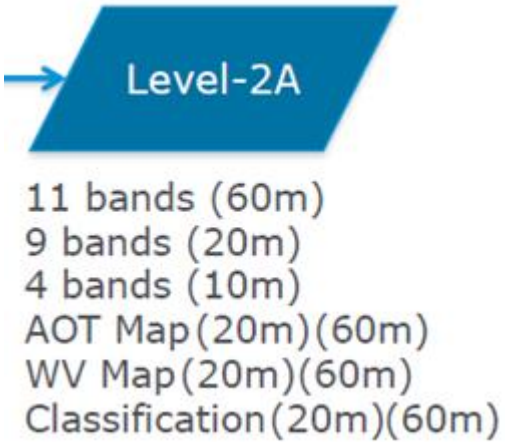
Look-up-table selection	Default
Aerosol type	Rural (maritime, auto)
Atm. profile	Summer (summer, winter)
Ozone content	Use metadata (select value of LUT)

GIPP	Default
Cirrus correction	Off
Visibility	Variable Visibility
WV correction	On
WV over water	Land average
Smooth WV map	100 m
Visibility	40 km
BRDF correction	No
Adjacency range	1 km

SEN2COR: INPUTS & OUTPUTS

- Input:
  - Level-1C ortho-image Top-Of-Atmosphere (TOA) reflectance products
    - ECMWF product TCO3
    - (AOT-field from ECMWF)
  - Look-up tables (rural & maritime aerosols)
  - DEM (default: SRTM v4 CGIAR) (or DTED provided by user)



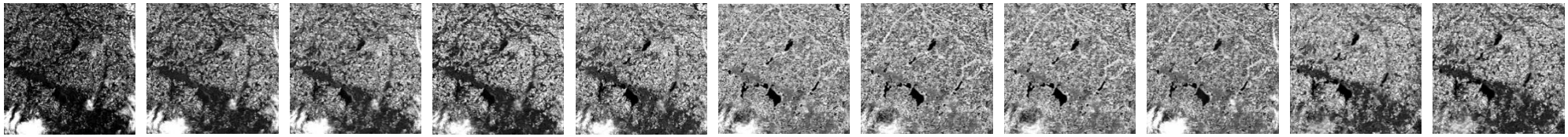


- Output (60m, 20m, 10m):
  - Bottom-Of-Atmosphere (BOA) corrected reflectance
  - Aerosol Optical Thickness (AOT) map
  - Water Vapour (WV) map
  - Scene Classification (SC) map
  - Quality Indicators for cloud and snow probabilities

SEN2COR OUTPUTS AT DIFFERENT SPATIAL RESOLUTIONS

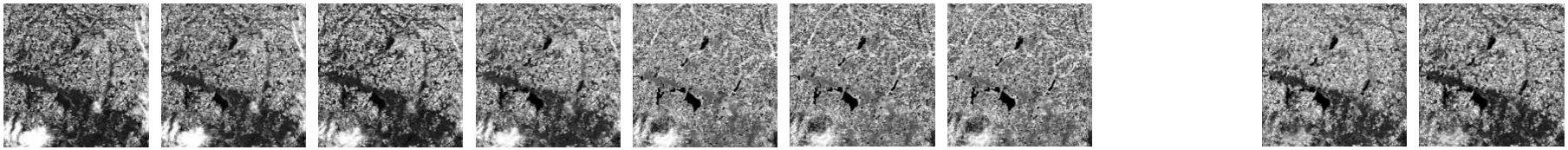
60 m product, BOA & quality

B1 443 nm | B2 490 nm | B3 560 nm | B4 665 nm | B5 705 nm | B6 740 nm | B7 783 nm | B8A 865 nm | B9 945 nm | B11 1610 nm | B12 2190 nm



Scene Classification | Cloud Confidence QI | Snow Confidence QI | AOT | WV

20 m product, BOA & quality



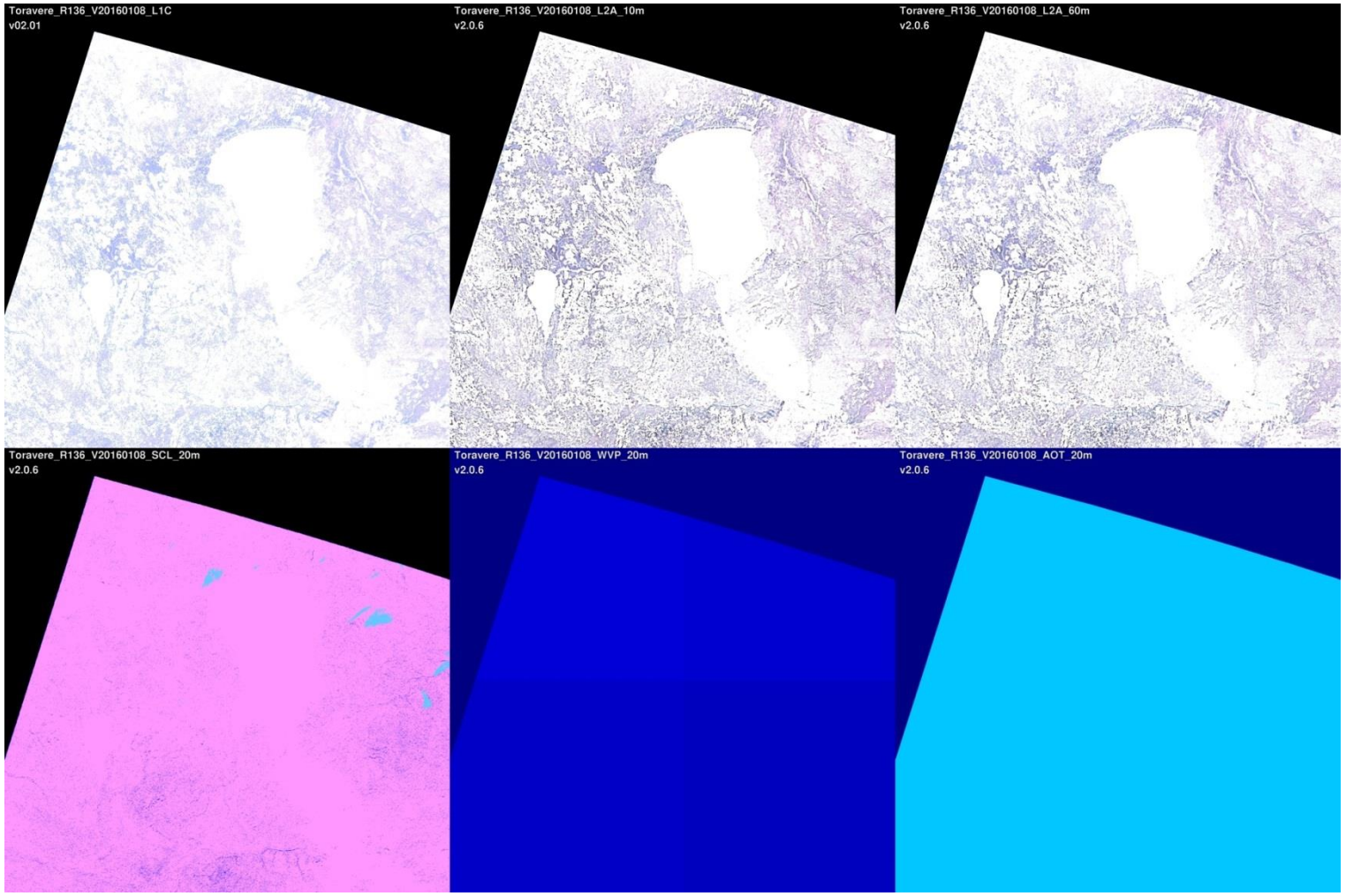
Scene Classification | Cloud Confidence QI | Snow Confidence QI | AOT | WV

10 m product, BOA

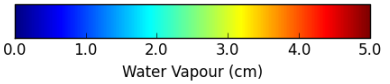
B2 490 nm | B3 560 nm | B4 665 nm | B8 842 nm

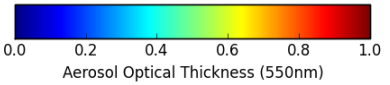
SEN2COR PROCESSING EXAMPLES

L1C | L2A 10m | L2A 60m



Label	Classification
0	NO_DATA
1	SATURATED_OR_DEFECTIVE
2	DARK_AREA_PIXELS
3	CLOUD_SHADOWS
4	VEGETATION
5	BARE_SOILS
6	WATER
7	CLOUD_LOW_PROBABILITY
8	CLOUD_MEDIUM_PROBABILITY
9	CLOUD_HIGH_PROBABILITY
10	THIN_CIRRUS
11	SNOW



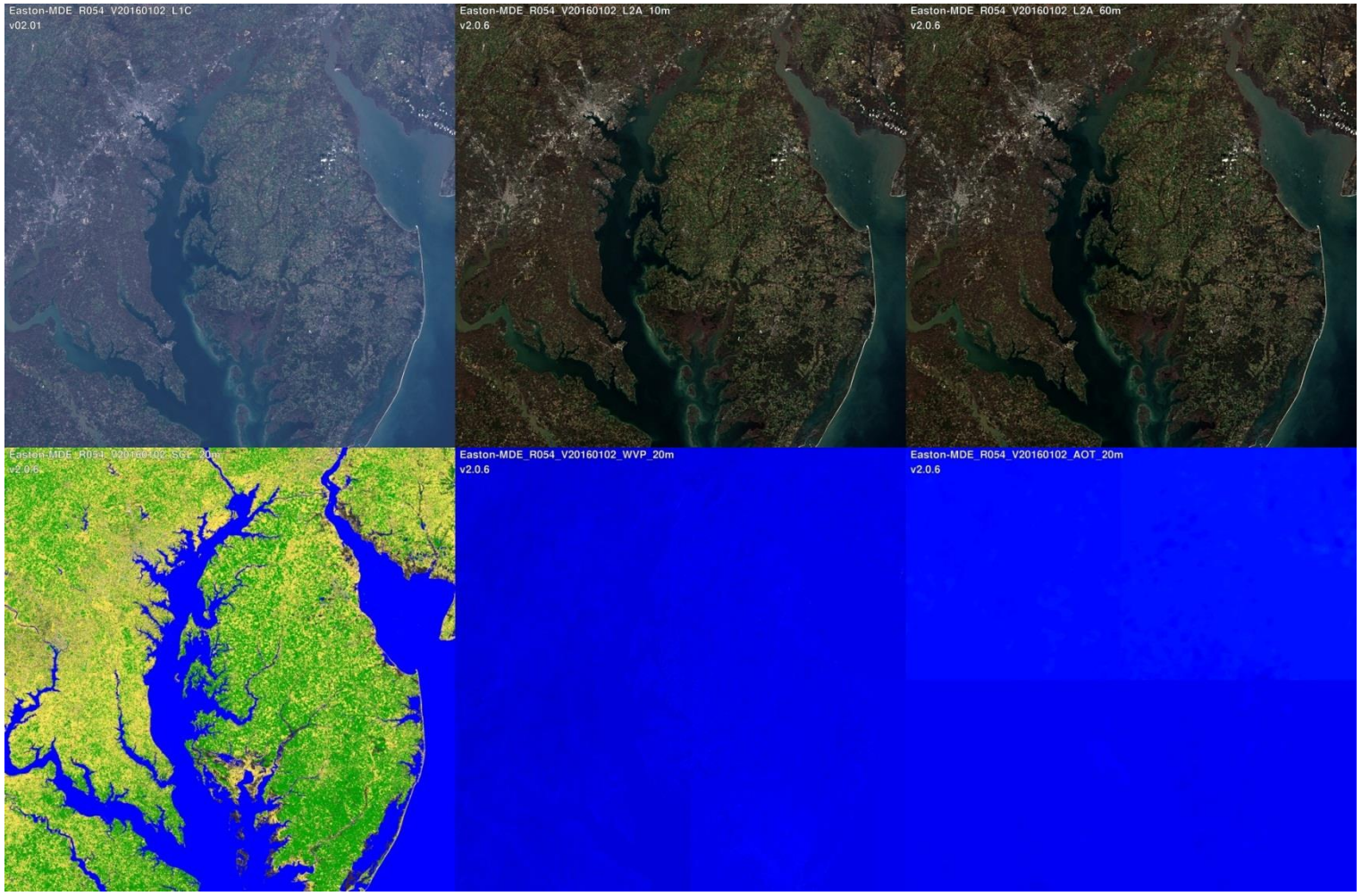


SCL | Water Vapour | AOT

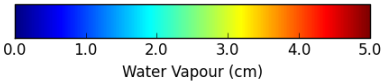
Example 1: Boreal, Flat, Forest, Lakes, Croplands, Toravere (EST), acquired on 8th of January 2016

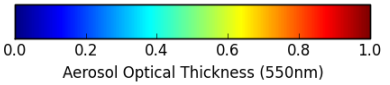
SEN2COR PROCESSING EXAMPLES

L1C | L2A 10m | L2A 60m



Label	Classification
0	NO_DATA
1	SATURATED_OR_DEFECTIVE
2	DARK_AREA_PIXELS
3	CLOUD_SHADOWS
4	VEGETATION
5	BARE_SOILS
6	WATER
7	CLOUD_LOW_PROBABILITY
8	CLOUD_MEDIUM_PROBABILITY
9	CLOUD_HIGH_PROBABILITY
10	THIN_CIRRUS
11	SNOW



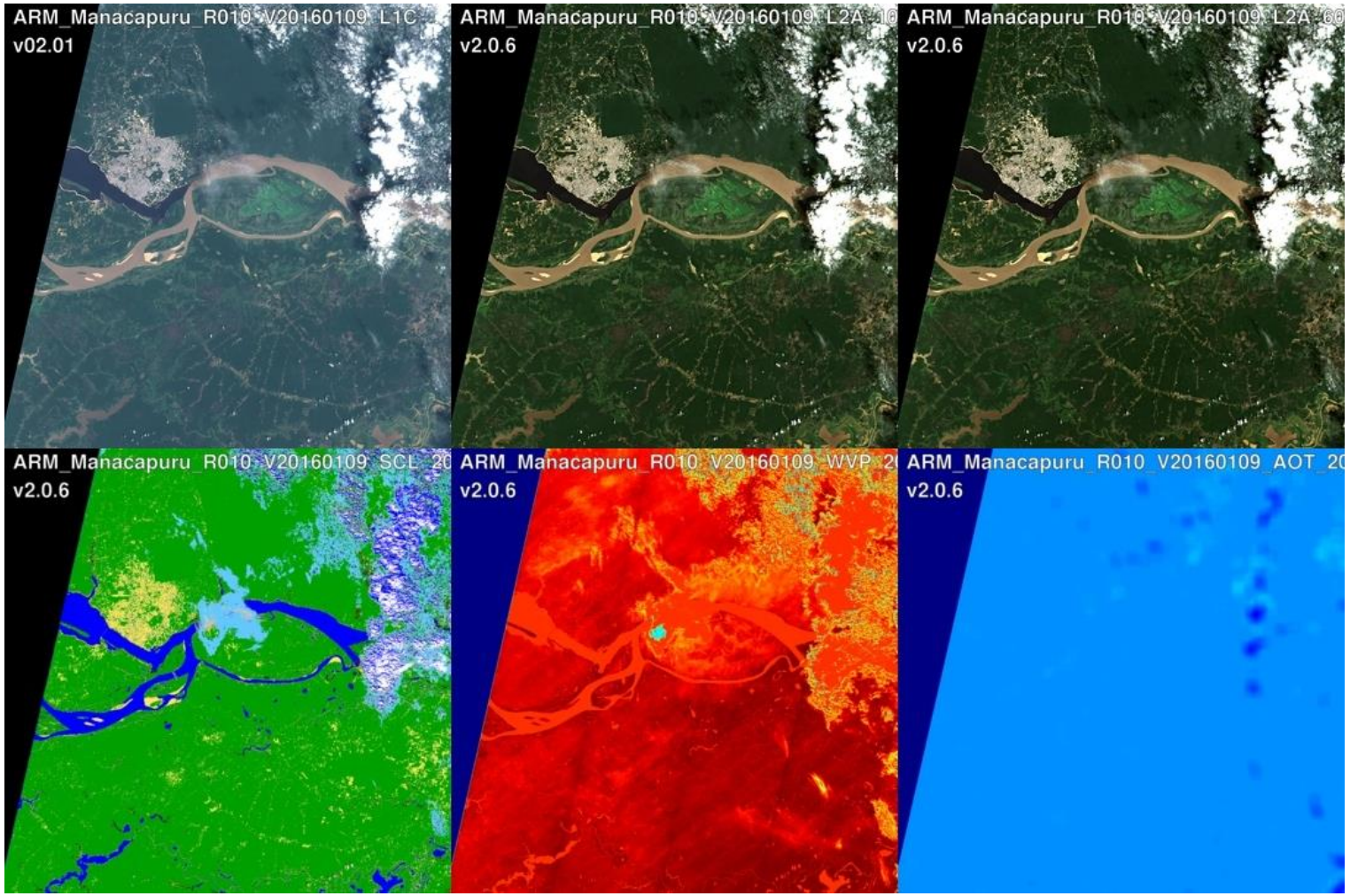


SCL | Water Vapour | AOT

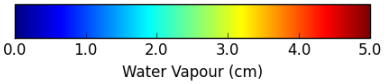
Example 2: MidlatitudeN, Flat, Forest, Croplands, Water, Urban
Easton-MDE (USA), acquired on 2nd of January 2016.

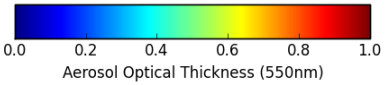
SEN2COR PROCESSING EXAMPLES

L1C | L2A 10m | L2A 60m



Label	Classification
0	NO_DATA
1	SATURATED_OR_DEFECTIVE
2	DARK_AREA_PIXELS
3	CLOUD_SHADOWS
4	VEGETATION
5	BARE_SOILS
6	WATER
7	CLOUD_LOW_PROBABILITY
8	CLOUD_MEDIUM_PROBABILITY
9	CLOUD_HIGH_PROBABILITY
10	THIN_CIRRUS
11	SNOW



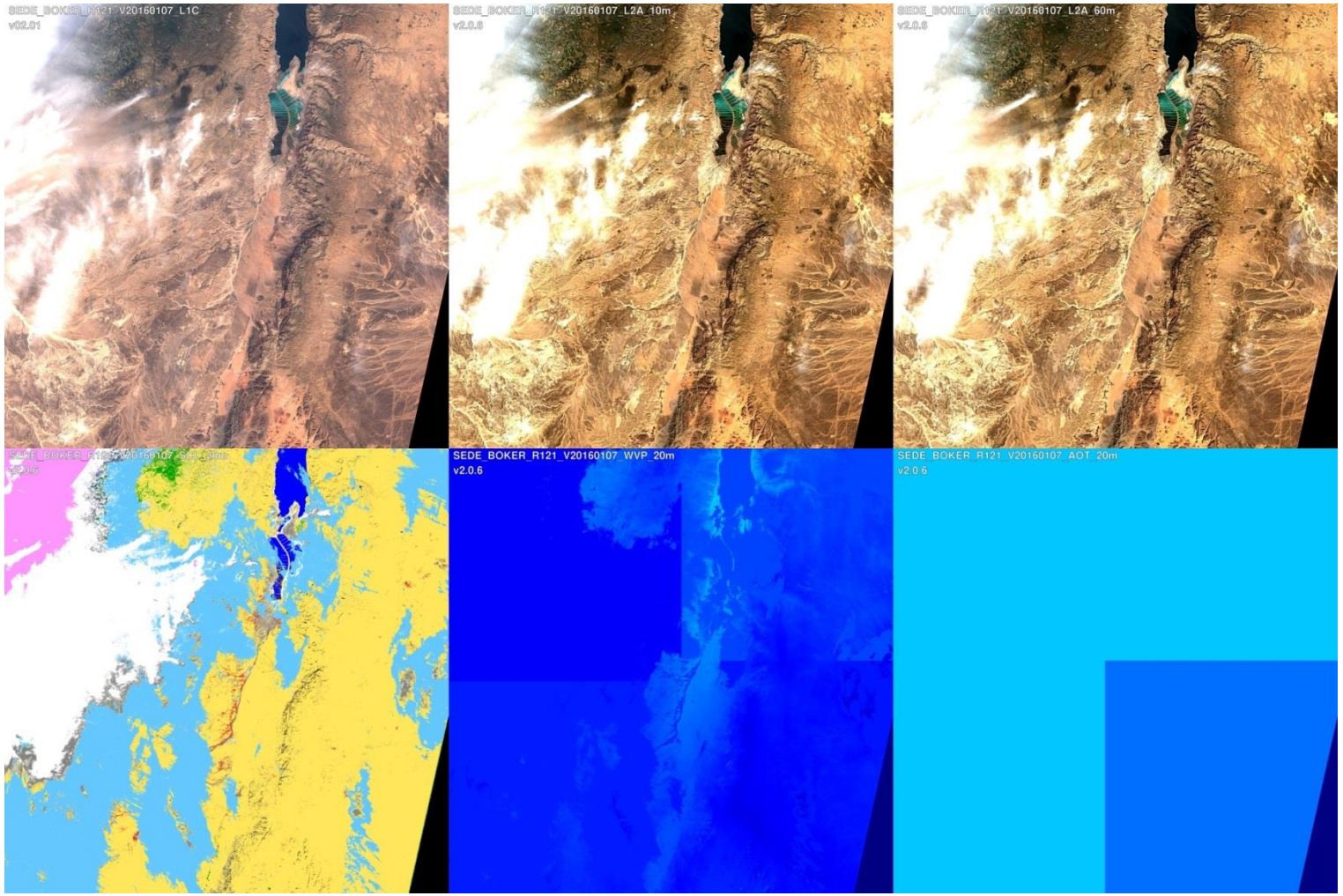


SCL | Water Vapour | AOT

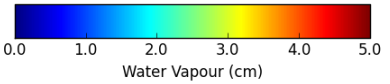
Example 4: Tropical, Flat, Tropical Forest, Water, ARM_Manacapuru (BRA), acquired on 9th of January 2016.

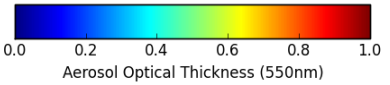
SEN2COR PROCESSING EXAMPLES

L1C | L2A 10m | L2A 60m



Label	Classification
0	NO_DATA
1	SATURATED_OR_DEFECTIVE
2	DARK_AREA_PIXELS
3	CLOUD_SHADOWS
4	VEGETATION
5	BARE_SOILS
6	WATER
7	CLOUD_LOW_PROBABILITY
8	CLOUD_MEDIUM_PROBABILITY
9	CLOUD_HIGH_PROBABILITY
10	THIN_CIRRUS
11	SNOW

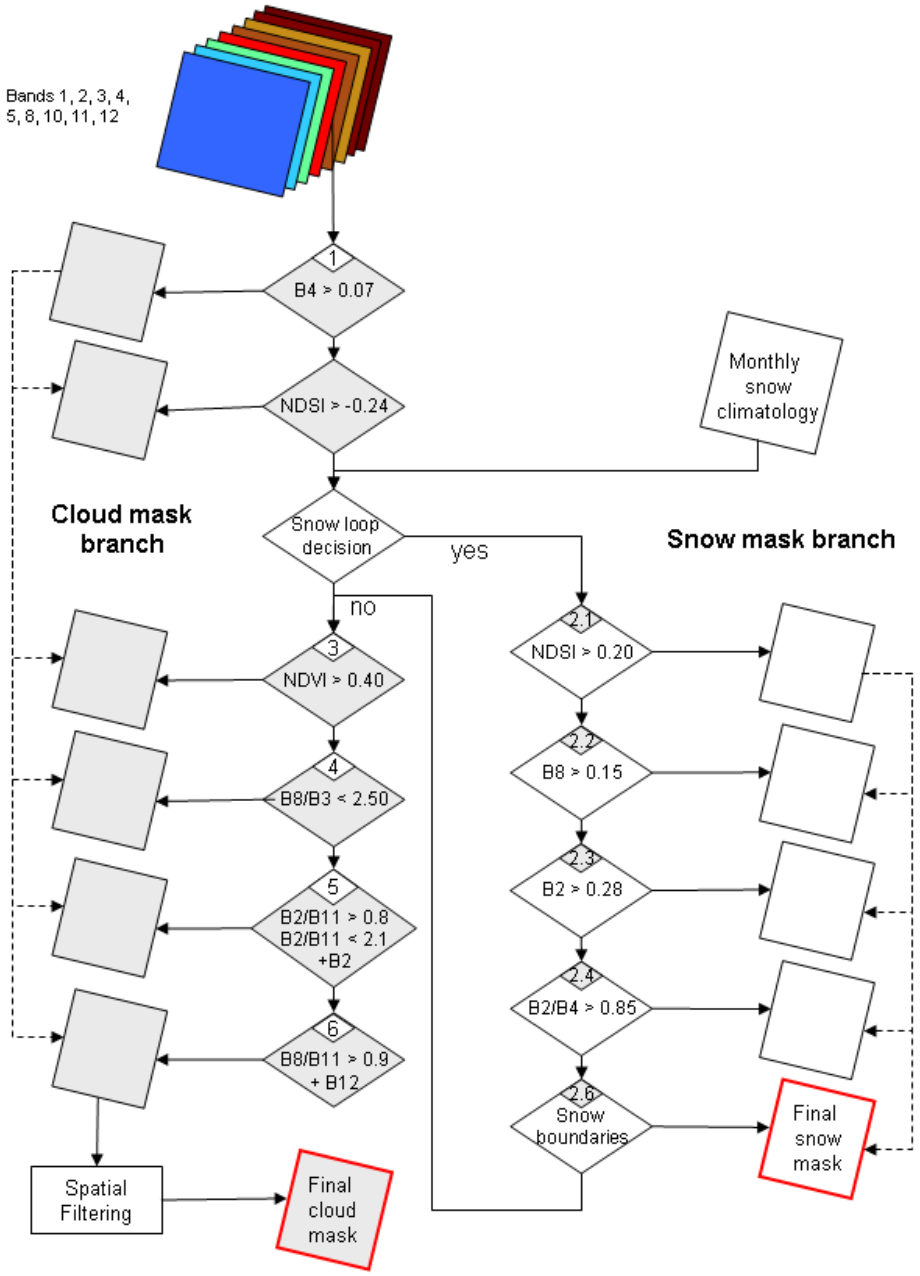


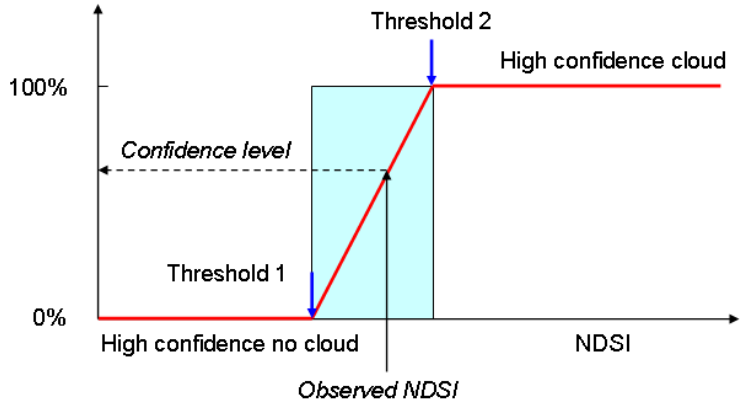


SCL | Water Vapour | AOT

Example 7: MidLatitudeN, Mountainous, Desert, SEDE_BOKER (ISR), acquired on 7th of January 2016

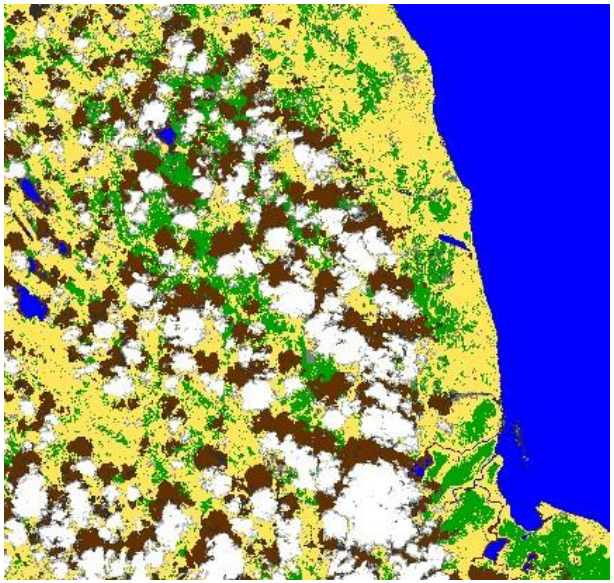
Cloud Screening and Classification Overview





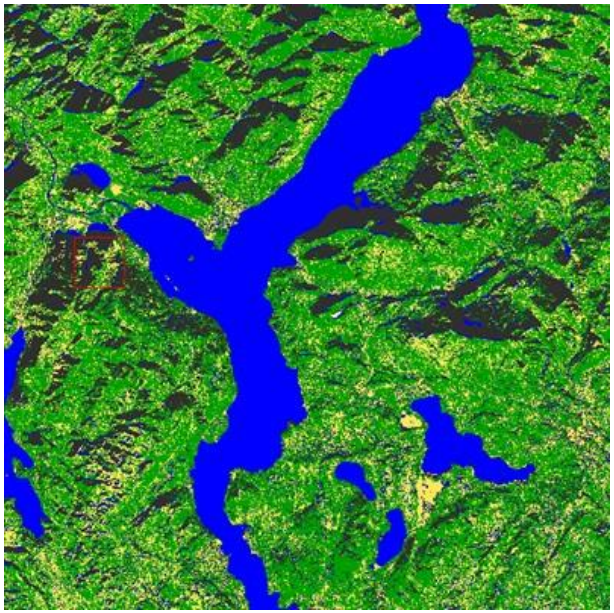
- Sequence of Threshold pairs
- Cloud Shadow Detection
- Topographic Shadows (DEM)
- Cirrus detection mitigation (DEM)

SEN2COR SHADOW DETECTION



➔ Cloud shadows

- Cloud shadow direction from solar angles
- Dark features identification

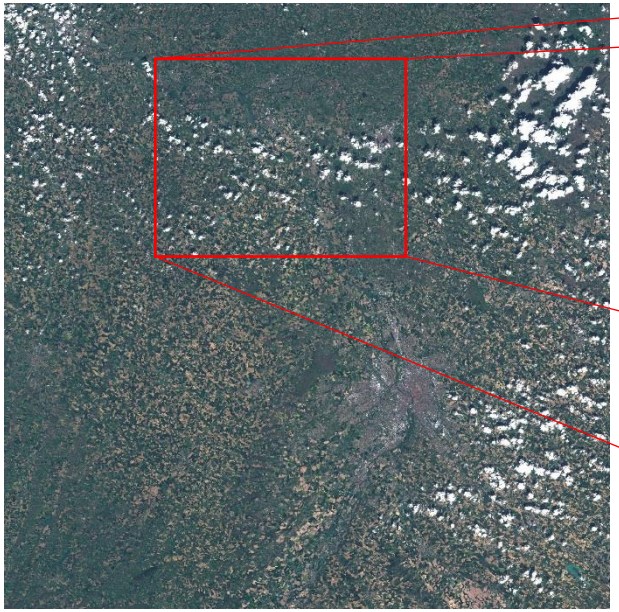


➔ Topographic shadows

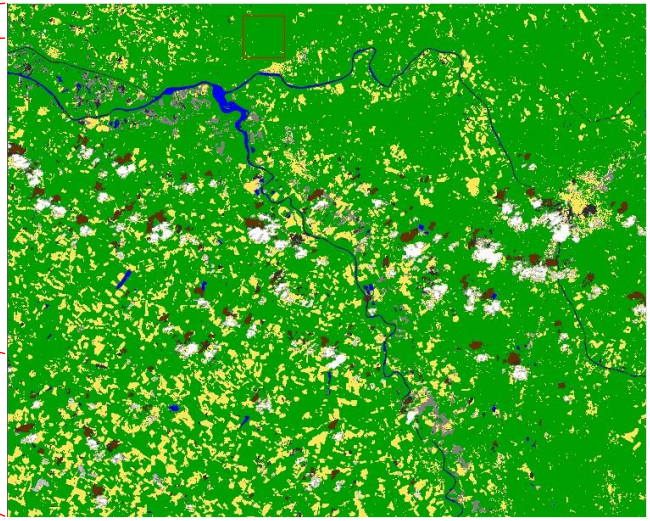
- Illumination map derived from solar position and Digital Elevation Model (DEM)
- DEM slope information used to filter high slope values

Cloud Screening and Classification Outputs

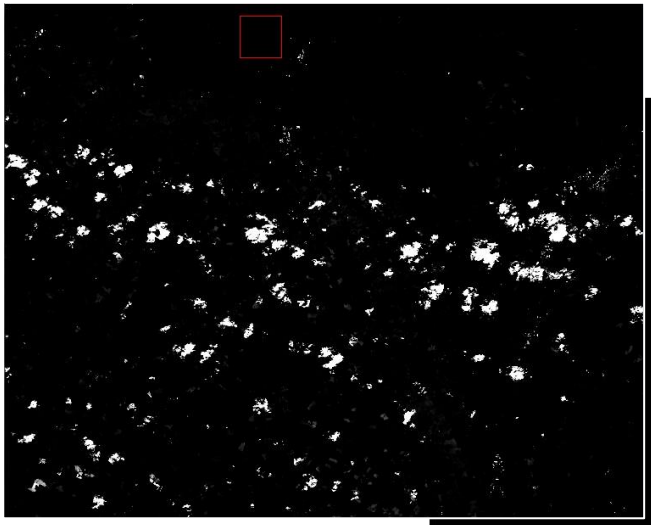
L1C Tile 31TCJ



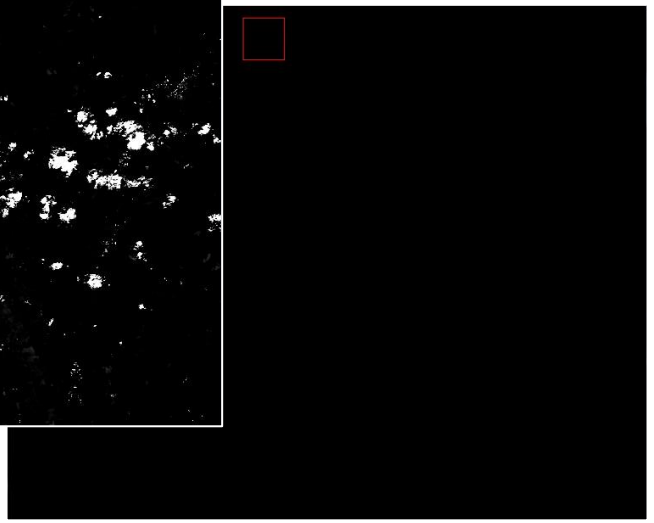
Scene Classification



0	No Data (Missing data on projected tiles) (black)
1	Saturated or defective pixel (red)
2	Dark features / Shadows (very dark grey)
3	Cloud shadows (dark brown)
4	Vegetation (green)
5	Bare soils / deserts (dark yellow)
6	Water (dark and bright) (blue)
7	Cloud low probability (dark grey)
8	Cloud medium probability (grey)
9	Cloud high probability (white)
10	Thin cirrus (very bright blue)
11	Snow or ice (very bright pink)



Cloud Confidence QI



Snow Confidence QI

AOT(550nm) Retrieval, Part 1: DDV Selection

- S2: uses B12(2.2 µm) & B8a(865 nm)

  L8: uses B7(2.2 µm) & B5(865 nm)

➔ compute surface ρ(2.2µm) for VIS=23km excluding water.
(Min. distance of DDV-pixels to clouds = 500 m) Then

a) $0.01 < \rho(2.2\mu m) < 0.05$ If less than 5% of scene pixels DDV, then

b) $0.01 < \rho(2.2\mu m) < 0.10$ If less than 5% of scene pixels DDV, then

c) $0.01 < \rho(2.2\mu m) < 0.12$

d) If < 2% DDV pixels, then set VIS to default value
(VIS=23 km corresponds to AOT=0.32)

e) Check water bodies: if ρ(water, 865 nm) < 0 for more than 1% of pixels, then

- decrease AOT550 until ρ(water, 865 nm) >= 0

AOT(550nm) Retrieval, Part 2: spectral correlation

Spectral correlation for DDV:

S2: B2(490 nm), B4(665 nm) & B12(2.2 µm)

L8: B2(490 nm), B4(665 nm) & B7(2.2 µm)

- ρ(0.665µm) = 0.5 ρ(2.2µm)
- ρ(0.490µm) = 0.5 ρ(0.665µm) + 0.005
- ρ(0.443µm) = 0.8 ρ(0.490µm)
- calculate VIS [AOT] from ρ(0.665µm)
- Non-reference pixels are assigned the average AOT550 of the DDV pixels
- Smoothing of AOT550 map to suppress noise (3 km box)
- Rescale path radiance to match ρ(0.443µm,DDV) & (0.490µm,DDV)

WATER VAPOR RETRIEVAL

- Atmospheric Precorrected Differential Absorption (APDA) technique
  Ref: Schläpfer et al. RSE, Vol. 65, 353-366 (1998)
- S2 Bands B8a (865 nm) and B9 (945 nm)

$$R_{APDA} = \frac{L(\rho,945) - L_p(945,W)}{L(\rho,865) - L_p(865)}$$

$$R_{APDA}(W) = a_0 \, exp(-a_1 W^{a_2})$$

$$W = \left(\frac{ln(R_{APDA}/a_0)}{-a_1} \right)^{1/a_2}$$

Equations are iterated using the precalculated LUTs with W=0.4 – 5.0 cm

SURFACE REFLECTANCE RETRIEVAL

➔ Flat terrain, 3 steps:

1. solve RT equation for ρ:

$$L = L_p + \frac{T\, E_g\, \rho^{(1)} / \pi}{1 - \rho^{(1)}\, s}$$

2. Calculate average (1 – 2 km box):

$$\bar{\rho} = \sum_{i,k=1}^{N} \rho^{(1)}(i,k)$$

3. Adjacency correction:

$$\rho(x,y) = \rho^{(1)}(x,y) + q\left\{\rho^{(1)}(x.y) - \bar{\rho}(x,y)\right\}$$

➔ Mountainous terrain:

complex, see references for details,
DEM required, includes empirical BRDF-correction

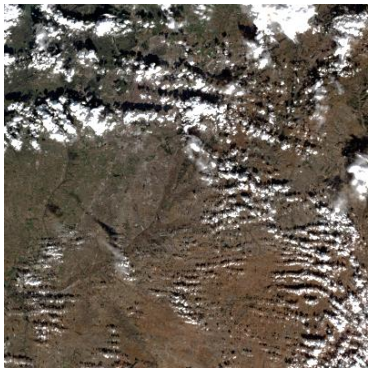
SEN2COR RELATED LITERATURE

1. R. Richter, J. Louis, U. Müller-Wilm, [L2A-ATBD] Sentinel-2 Level-2A Products Algorithm Theoretical Basis Document, S2PAD-ATBD-0001, version 2.0, 2012
2. U. Müller-Wilm, [L2A-IODD] Sentinel-2 MSI – Level-2A Input Output Data Definition, issue 1.0, S2PAD-VEGA-IODD-0001, 2014
3. U. Müller-Wilm, [L2A-PDD] Sentinel 2 MSI - Level 2A Product Definition, S2PAD-VEGA-PD-0001 [4.4].pdf, 2016
4. U. Müller-Wilm, [L2A-PSD] Sentinel 2 MSI - Level 2A Product Format Specifications Technical Note, S2PAD-VEGA-TN-PFS-0001 [1.6], 2016
5. U. Müller-Wilm, [L2A-SRN] Sen2Cor 2.2.1 - Software Release Note, ESA-EOPG-CSCGS-TN-0014[2.2.1], 2016
6. Gascon, F. et al., Copernicus Sentinel-2 Calibration and Products Validation Status. Preprints 2016, 2016100078 (doi: 10.20944/preprints201610.0078.v1).

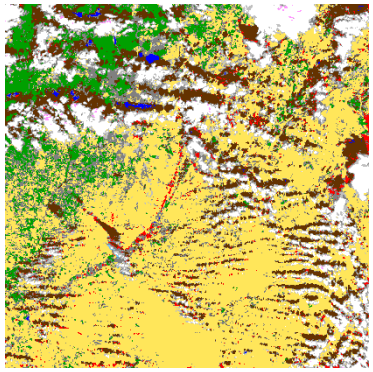
Validation: Cloud Screening and Classification (CSC)

➔ Validation steps

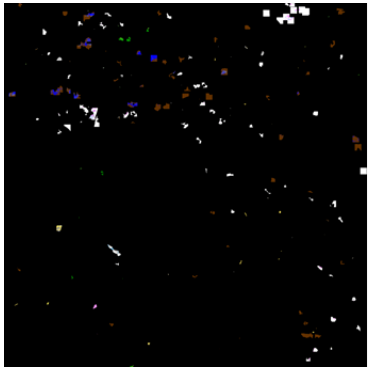
- Reading images (full granule)
- Stratified random sampling
- Pixel/area labelling by user (visual)
- Creation of reference image
- Confusion matrix,
  precision, recall and overall accuracy



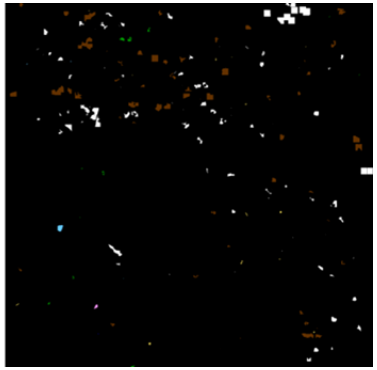
TOA RGB



Scene Classification



Ground truth
classification image



Sen2Cor
classification image

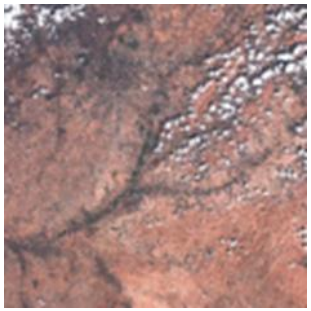
➔ Results of CSC validation:

- Mean overall precision for all examples: (80 ± 7) %

VALIDATION: CSC CONFUSION MATRIX

	Sen2cor class	Reference Class											Sum	Precision
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)		
saturated_or_defective	(1)	**0**	0		0	0	0	0	0	0	0	0	0	none
dark_area_pixels	(2)	0	**0**		0	0	0	0	0	0	0	0	0	none
clouds_shadows	(3)		2109	**26088**	2	44	15	1063	1	0	0	0	29322	0,89
vegetation	(4)	0	2	1	**3671**	1959	0	6	0	0	0	0	5639	0,65
bare_soils	(5)	0	0	0	47	**4615**	0	820	494	559	0	0	6535	0,71
water	(6)	0	339	42	11	24	**9905**	25	0	0	0	0	10346	0,96
cloud_low_probability	(7)	0	0	0	1	52	0	**59**	16	8	12	0	148	0,40
cloud_medium_probability	(8)	0	0	0	0	54	0	161	**232**	816	25	0	1288	0,18
cloud_high_probability	(9)	0	0	0	0	30	8	294	3372	**66447**	1151	1432	72734	0,91
thin_cirrus	(10)	0	0	0	0	0	0	0	0	0	**0**	0	0	none
snow	(11)	0	0		0	0	0	0	0	0	0	**0**	0	none
average	Sum	0	2450	26131	3732	6778	9928	2428	4115	67830	1188	1432	**126012**	

- Overall accuracy: 88 %
- Water (6) and cloud, high probability (9) exhibit similar high precision for all test scenes.
- Vegetation (4), bare soils (5), dark_area_pixels(2) and clouds_shadows (3): precision varies from scene to scene
- Cloud low and medium probability (7,8): generally remarkable lower precision



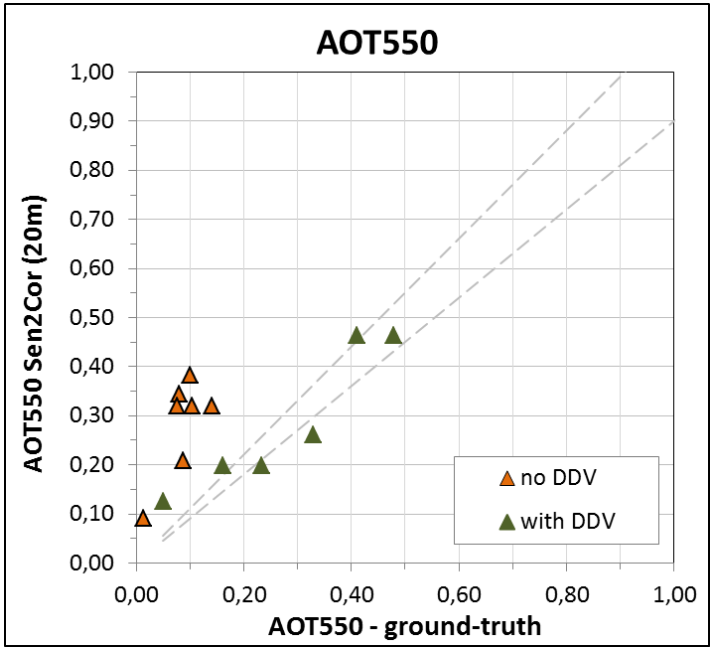
Granule: T30TVK
Date: 18.08.2015
Region: Spain, Madrid area

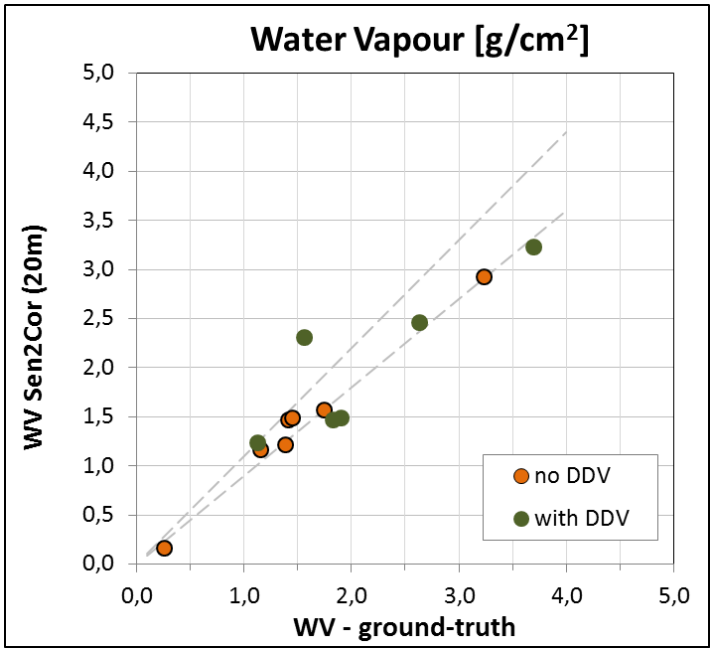
VALIDATION: AOT AND WV RETRIEVAL

- Validation steps (AOT & WV)
  - Run Sen2Cor with default configuration
  - Extract 9×9 km² subset around sunphotometer
  - Compute AOT statistics
  - Compute Water Vapor (WV) statistics
  - Download and process sunphotometer data as reference
  - Compare Sen2Cor output with reference

- Results of AOT validation (samples up to 50% cloud cover):
  - mean AOT difference: 0.05 with DDV-pixels present.
    Maximum difference: 0.075
  - Aerosol estimation fails, if no DDV-pixels in the image

- Results of WV validation (samples up to 50% cloud cover):
  - mean WV difference: 0.25 g/cm²
    Maximum difference: 0.75 g/cm²
  - Less influence of missing DDV pixels





Acknowledgment: We thank the PI investigators and their staff for establishing and maintaining the AERONET sites used in this investigation.

VALIDATION: BOA-PRODUCT

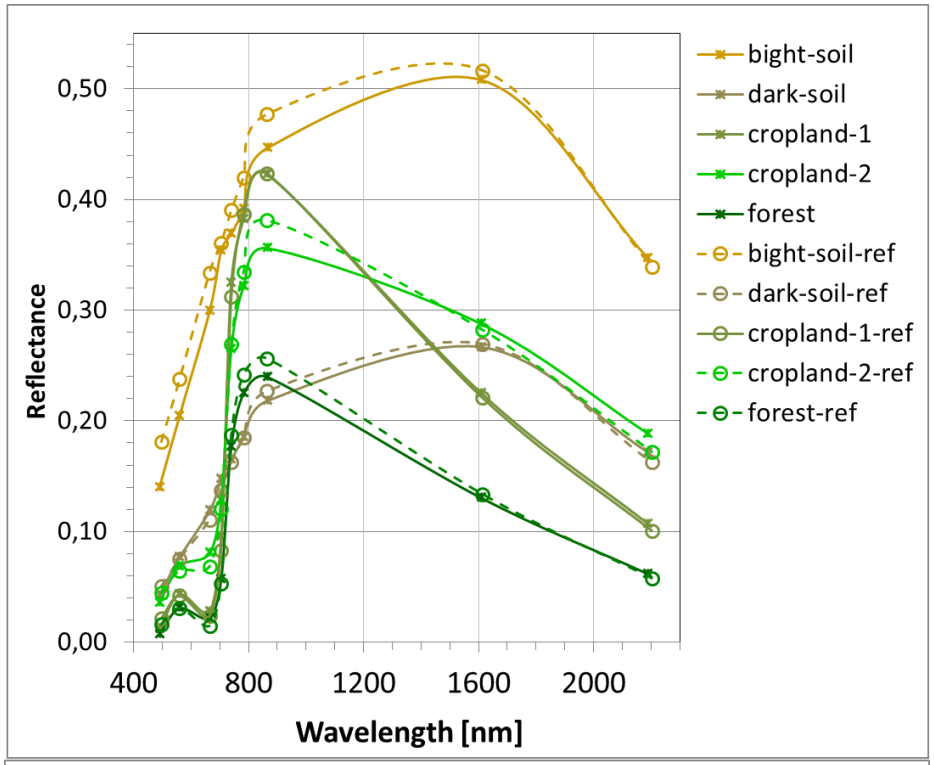
- Validation steps (BOA)
  - Run Sen2Cor with default configuration
  - Generate reference dataset running Sen2Cor with AOT = AERONET value
  - Compare Sen2Cor output with reference

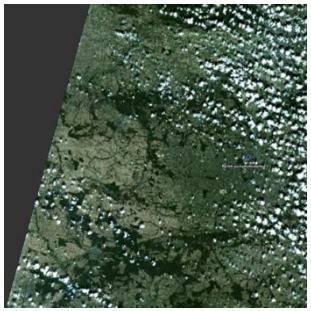
- Subset 9x9 km around sunphotometer:

  AERONET: AOT = 0.23 WV = 2.63 cm

  Sen2Cor: AOT = 0.20 WV = (2.46 ±0.1) cm

- Results:
  - Expected spectral dependency for reflectance spectra of for different surface types
  - Reflectance difference between Sen2Cor and reference up to 0.04
  - Leading to NDVI-uncertainty up to 0.06





Granule: T34UDC
Date: 14.08.2015
Region: Poland, Belsk area

SEN2COR VALIDATION OUTCOME

➔Scene classification:

- Mean overall precision for Scene classification is (80 ± 7) %
- Highest precision for classes water and high probability cloud
- Precison for Classes vegetation, bare soils, dark_area_pixels and clouds_shadows is high for some images and low for other

➔AOT and WV retrieval:

- mean AOT difference: 0.05 if DDV pixels are existing in the granule.
- Aerosol estimation fails, if there are no DDV-pixels in the image.
- mean WV difference: 0.25 g/cm^2, less influenced by missing DDV pixels

➔BOA-reflectance retrieval:

- Reflectance difference between Sen2Cor and reference up to 0.04
- Only partly agrees within the target accuracy of 5% relative for BOA-reflectance [(requirement S2-MP-200), [MPC-ROCVP], p.17]

SEN2COR OUTLOOK

➔ Sen2Cor is available at:
http://step.esa.int/main/third-party-plugins-2/sen2cor/

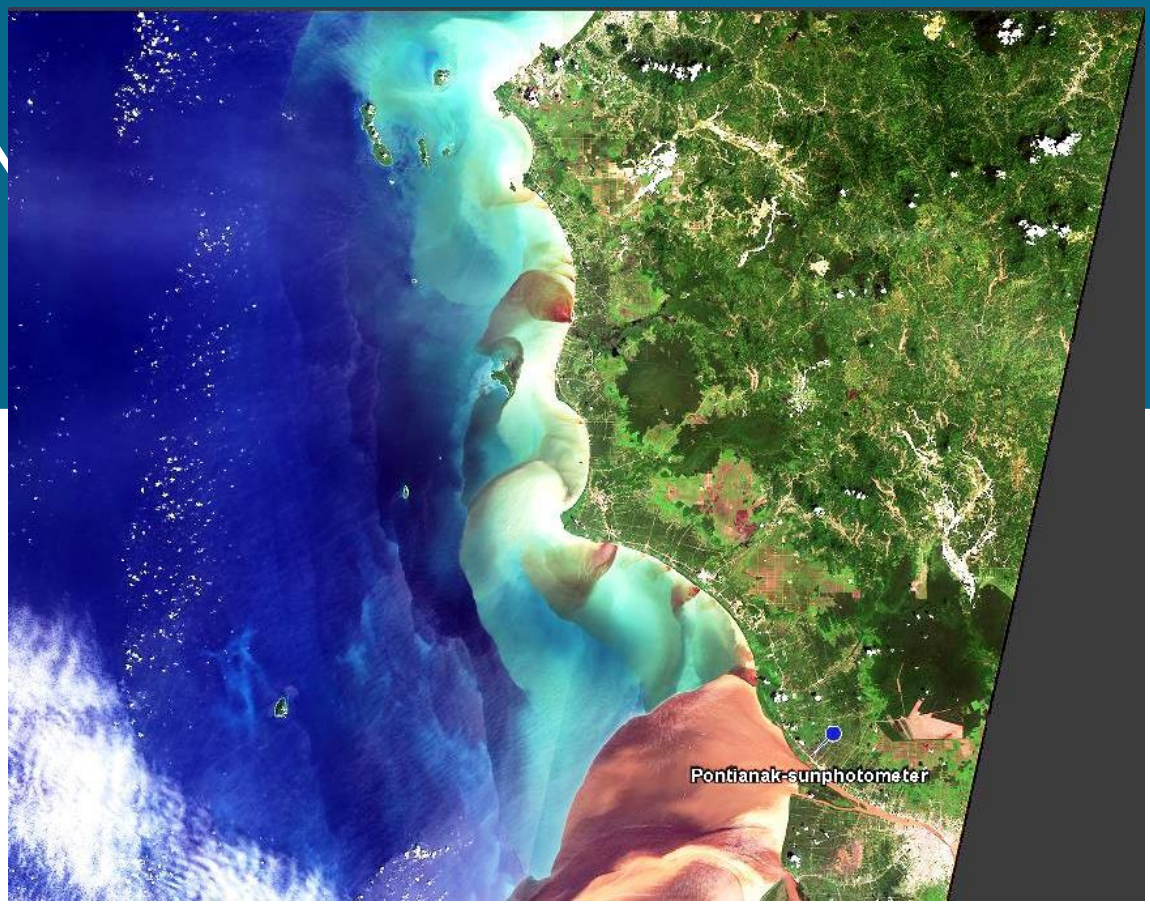
➔ Sen2Cor 2.2.2 list of main evolutions:

- Improved DEM handling
- L2A products with JPEG2000 geo-information support
- Option to activate / deactivate terrain correction independently from DEM (usage for CSC, AOT & WV estimation, but no terrain correction).

➔ Sen2Cor list of main future evolutions:

- Use ECMWF aerosol information in case of missing DDV-pixels

THANK YOU FOR Y



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