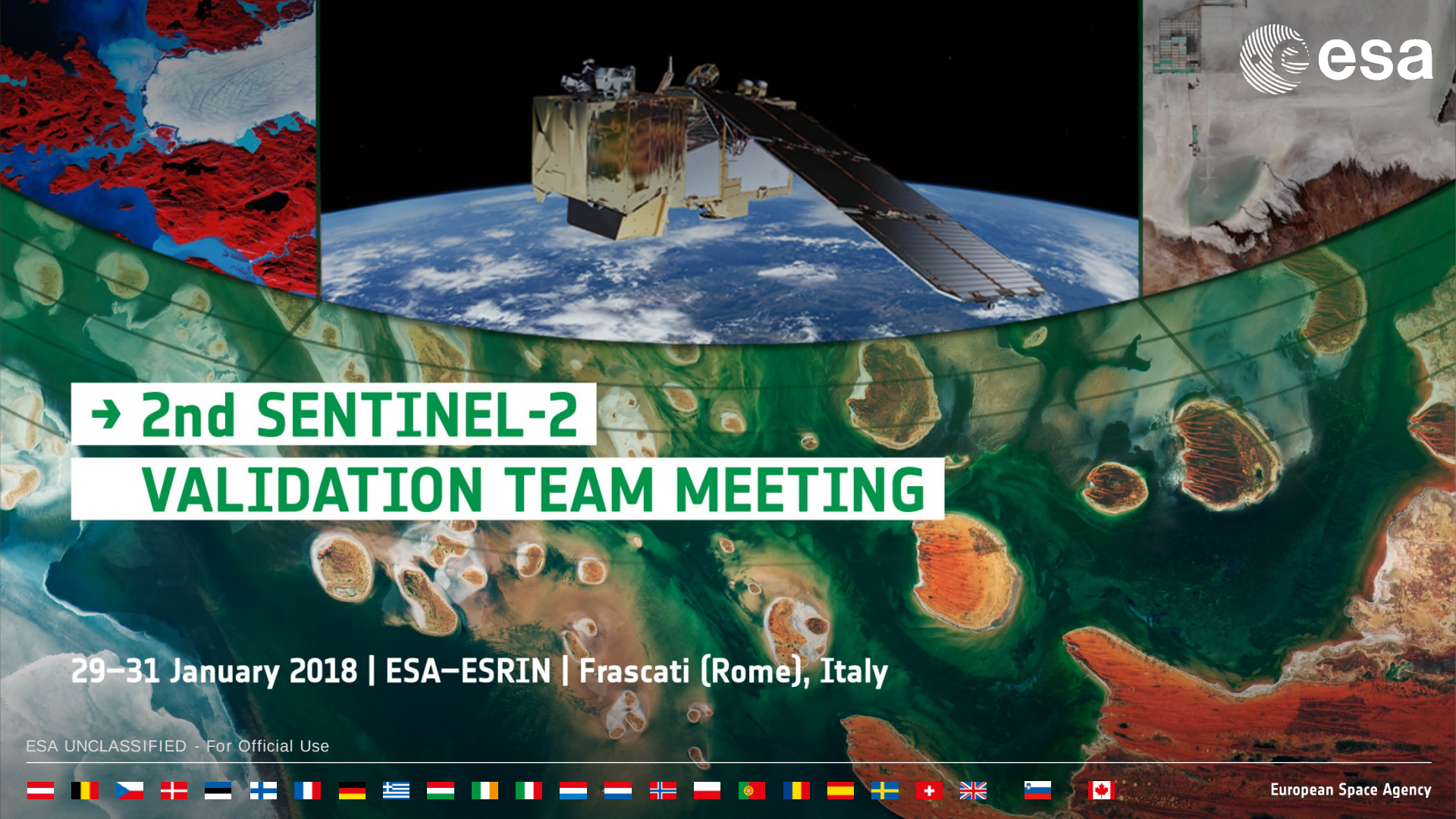
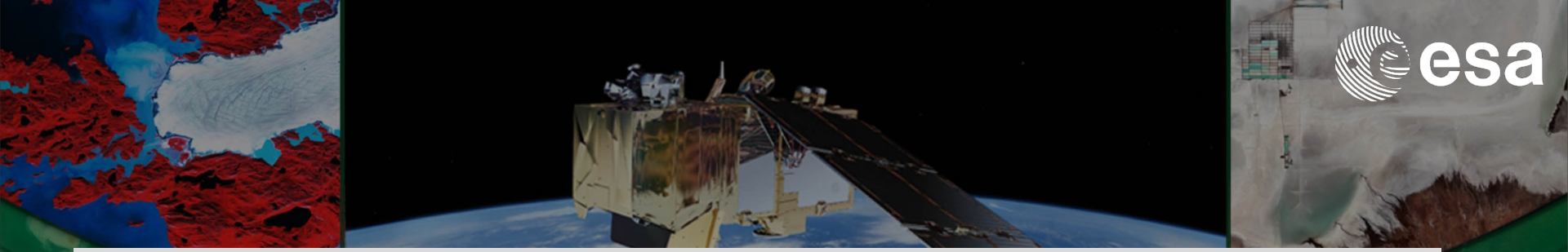


→ 2nd SENTINEL-2 VALIDATION TEAM MEETING

29–31 January 2018 | ESA–ESRIN | Frascati (Rome), Italy



The Sen2Cor and MAJA cloud masks and classification products

Magdalena Main-Knorn, Jerome Louis, Olivier Hagolle, Uwe Müller-Wilm, Kevin Alonso

Outline

1. Sen2Cor
2. MAJA
3. Comparison and Validation procedure
4. Results and Examples
5. Conclusions

1. SEN2COR Processor

- Atmospheric correction processor, developed by Telespazio on behalf of ESA
- Mono-temporal processor: corrects single-date Sentinel-2 L1C Top-Of-Atmosphere (TOA) products from the effects of the atmosphere and delivers a L2A Bottom-Of-Atmosphere (BOA) reflectance product
- Additional outputs: Aerosol Optical Thickness (AOT) map, Water Vapour (WV) map and Scene Classification (SCL) map with Quality Indicators for cloud and snow probabilities, in JPEG 2000 image format
- L2A data production run on the systematic basis over Europe with dissemination through the Copernicus Open Access Hub since May 2017
- Processor can be freely downloaded (new Version 2.5) and used for processing L1C images

2. MAJA Processor

- Atmospheric correction processor, developed by CNES, DLR and CESBIO
- MAJA uses a combination of multi-spectral and multi-temporal (Sentinel-2 time series) criteria to detect invalid pixels, and to estimate AOT before correcting for atmospheric effects
- Multi-temporal algorithm based on the assumption that surface reflectance tends to change slower in time than cloud cover
- Corrects Sentinel-2 L1C TOA products from the effects of the atmosphere and delivers a L2A BOA reflectance products
- Additional outputs: Aerosol Optical Thickness (AOT), Water Vapour (WV), and set of masks for clouds, cloud shadows, topographic shadows, snow and water
- L2A data production (7M km^2) run by CNES, >60 000 L2A products freely available
- Processor (V1.0) is available as executable code, for linux RedHat/CentOS https://logiciels.cnes.fr/en/content/maja

Sen2Cor and MAJA Masking and Classification

	MAJA	SEN2COR
Algorithm	Multi-temporal and multi-spectral	Mono-temporal and multi-spectral
Classes	clouds (+cirrus), cloud shadows, topographic shadows, water and snow	saturated/defective, dark area, cloud shadows, vegetation, non-vegetated, water, unclassified, cloud medium probability, cloud high probability, thin cirrus, snow
Methods	thresholds, reflectance temporal variation; tests of the local temporal correlation; band ration and indices	thresholds on L1C spectral bands; Band ratios and indices
Outputs	8 bit set of binary masks	Scene Classification (SCL) map, Quality Indicators for cloud and snow probabilities
L2A spatial resolution	240m (time*2 if resolution 120)	20m, 60m
Dilation	240m	-
Total L2A Processing time	~20min	~30min

3. Validation and Comparison procedure

- Allocation key to consolidate Sen2Cor and MAJA classes for comparison:

MAJA class	Sen2Cor class
Clouds	Cloud_medium_probability, Cloud_high_probability, Thin cirrus
Cloud shadows	Cloud shadows
Water	Water
Snow	Snow
Topographic shadow	Dark pixel area
Land	Vegetation Non-vegetated Unclassified

- Comparison of MAJA V2 and Sen2Cor 2.5

- Validation test-sites (MAJA-based)

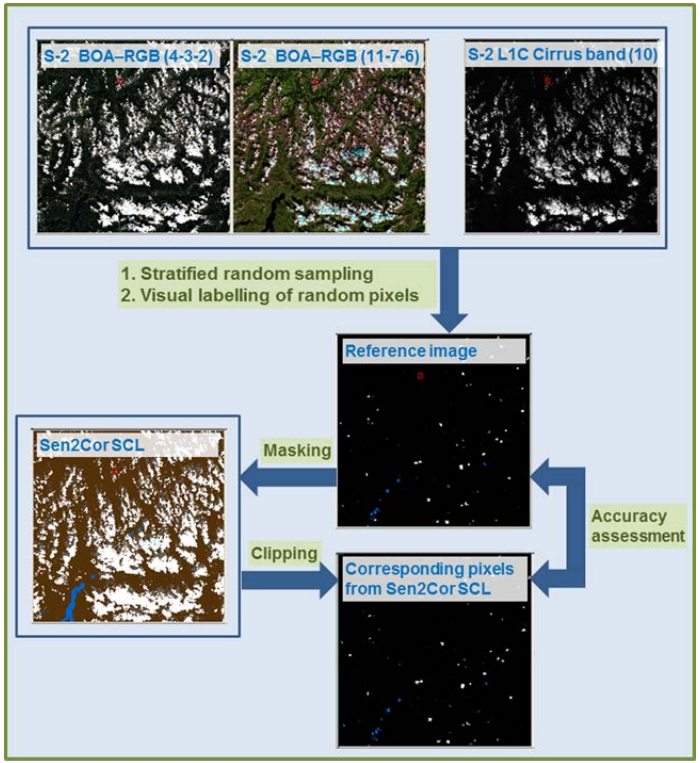
  cloud cover: 3-73%

  good representativeness

Site	Tile	Date
Alta Floresta(Brazil)	21LWK	2016/06/01
Davos (Switzerland)	32TNS	2016/09/09
Davos (Switzerland)	32TNS	2016/05/22
Hyytiala (Finland)	35VLJ	2016/05/23
Ispra (Italy)	32TNR	2016/04/22
Mongu (Zambia)	34LGH	2016/10/03
Mongu (Zambia)	34LGH	2016/10/23
Ouarzazate (Morocco)	29RPQ	2016/04/17
Railroad Valley (USA)	11SNC	2016/05/09
Railroad Valley (USA)	11SNC	2016/06/28
Sede Boker (Israel)	36RXV	2016/05/06

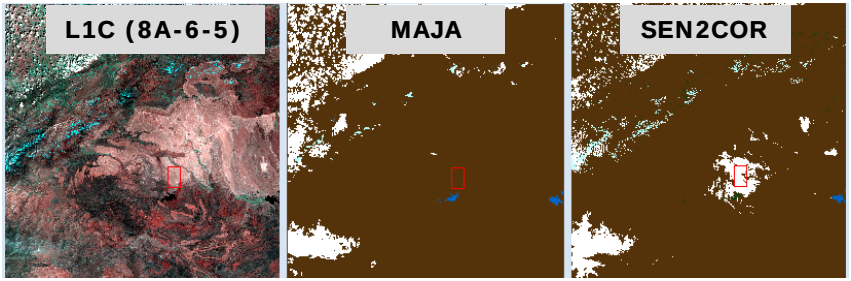
3. Validation and Comparison procedure

- Validation steps:
  - Stratified random sampling
  - Pixel/area labelling (visually) based on: S2 bands 4-3-2, 8A-5-6 & 12-11-8A spectral profiles, QIs, L1C cirrus band, Google data arch.
  - Creation of the validation image (reference image)
  - Creation of the corresponding subset of the classification image
- Reported: confusion matrix user's, producer's accuracies (or commission and omission errors), overall accuracy



Davos (Switzerland) aquired on 09.09.2016, S2A_MSIL1C_20160909T154459_A006354_T32TNS

3. Validation procedure limitation



- Stratified random sampling is based on MAJA masks – it can bias validation results, where Sen2Cor classification failed;
- Reference samples set is inbalanced, semi-proportional to the class area
- Total number of sampels over land is ~416 000 (~23% of total reference sampels) but for some products not sufficient enough
- Definition of thin cirrus and visual interpretation is subjective
- Internal test on the subjectivity of the validation method (4 validating persons, 2 products) revealed quite stable results (st.dev of classification accuracy ~5-6%). More extended tests are required.
- In preparation classification validation protocol for L2A to assure validation quality and comparability between algorithms

4. Preliminary Validation Results

	MAJA V2		SEN2COR 2.5	
	commission	omission	commission	omission
Clouds	2,9	6,6	5,0	3,7
Cloud shadows	18,9	44,0	2,9	60,0
Water	18,9	29,2	13,6	11,5
Snow	23,2	1,4	20,9	7,2
Topographic shadows	86,2	90,4	97,8	57,4
Land	34,3	21,1	16,2	9,8
OA complete	90,2 (±7)		92,7 (±4)	
Pixel validated (average):				166685
Total of validated pixels:				1833536

All classes comparison:

- Cloud detection works very good for both processors
- Cloud shadows classification shows low performance
- Topographic shadows are very challenging to classify

- Detection of clear land and water pixels for 11 products seems to be a little bit higher by Sen2Cor but… it could be biased by the number of validated samples!
- Snow is well recognized but overestimated in some places

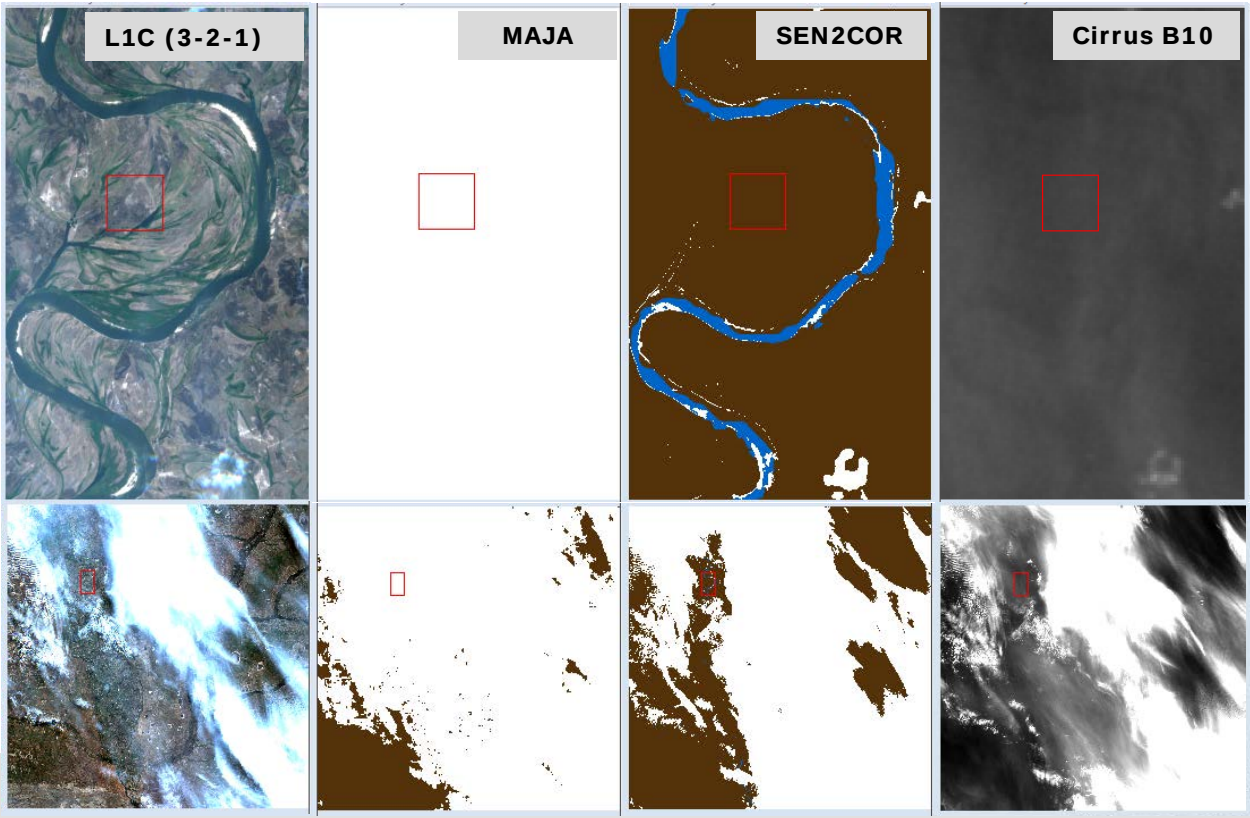
4. Preliminary Validation Results

Valid and invalid pixels comparison:

- Issues related to stratification based on MAJA masking
- Invalid pixels detection is correct for both processors
- Two poor results of MAJA related to decision on thin cloud threshold
- Overall accuracy for both processors is high(>94%), and may improve with the increasing number of validated products and further processor evolution.

	Overall accuracy		
Test-site	**MAJA**	**SEN2COR**	***Comment***
Alta Floresta	97,8	96,8	*Low number of land references*
Hyytiala	95,9	98,7	
Davos	92,4	94,7	
Davos2	81,5	90,6	*Thin cirrus confusion*
Ouarzazate	99,6	93,9	*Stratification bias*
Mongu	85,2	96,2	*Thin cirrus confusion*
Mongu2	99,3	95,4	
Ispra	93,0	95,9	
Sede Boker	96,3	97,3	*Stratification bias*
Railroad Valley	95,8	92,5	*Stratification bias*
Railroad Valley 2	95,9	92,2	*Low number of land references*

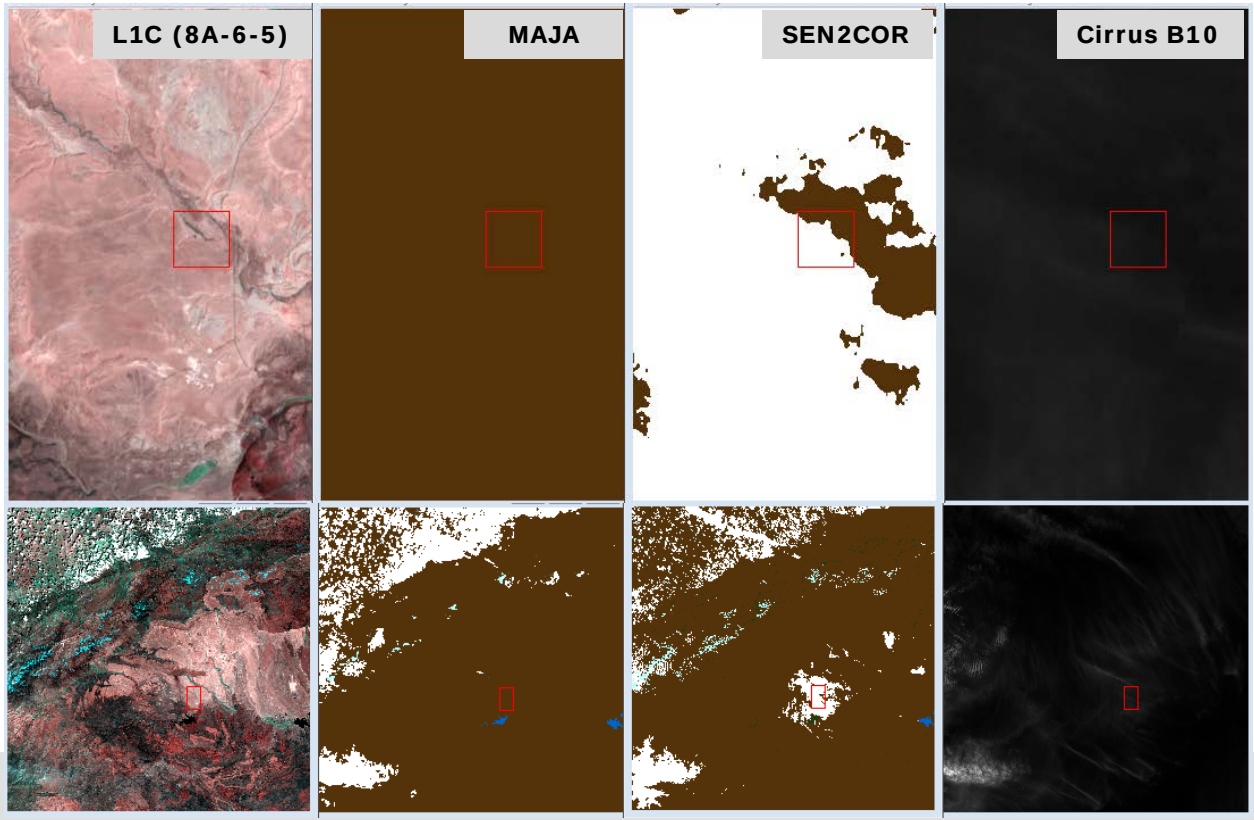
4. Validation Examples



- Definition of thin cirrus and visual interpretation is subjective & challenging
- Omission is for some applications more critical than commission error
- According to threshold used, MAJA shows commission and Sen2Cor omission errors in thin clouds detection

Mongu (Zambia) 03.10.2016;
L1C_T34LGH_A006696_20161003T084305

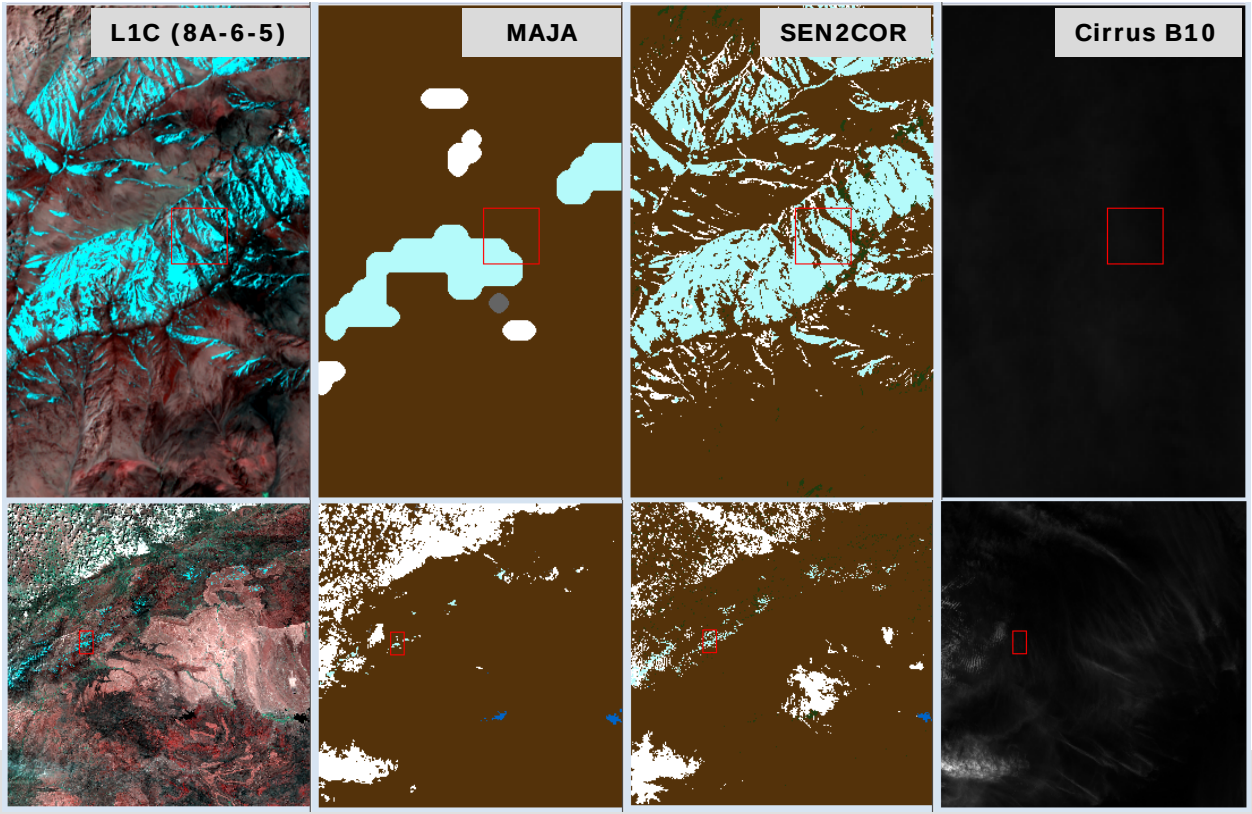
4. Validation Examples



- No cloud here
- Sen2Cor misclassifies bright surface as a compact cloud
- Here, MAJA provides higher accuracy than Sen2Cor

Quarzazate (Morocco) 17.04.2016;
L1C_T29RPQ_A004281_20160417T111159

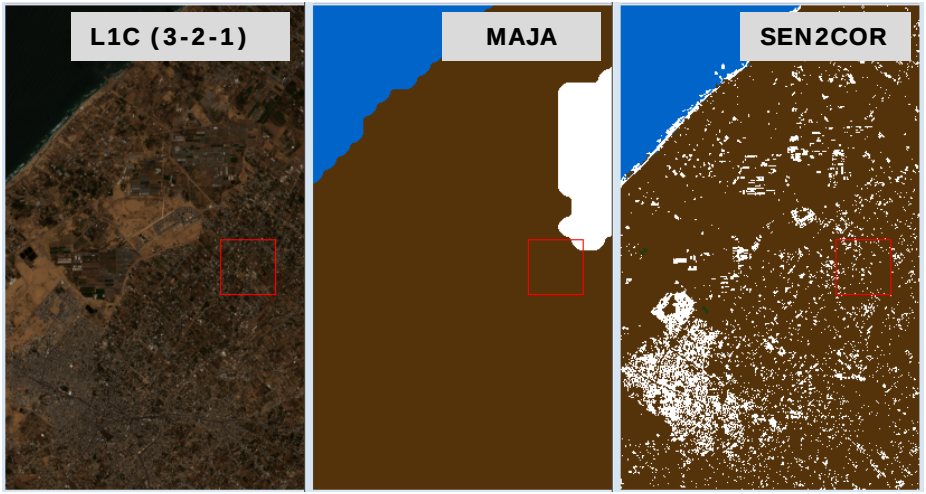
4. Validation Examples

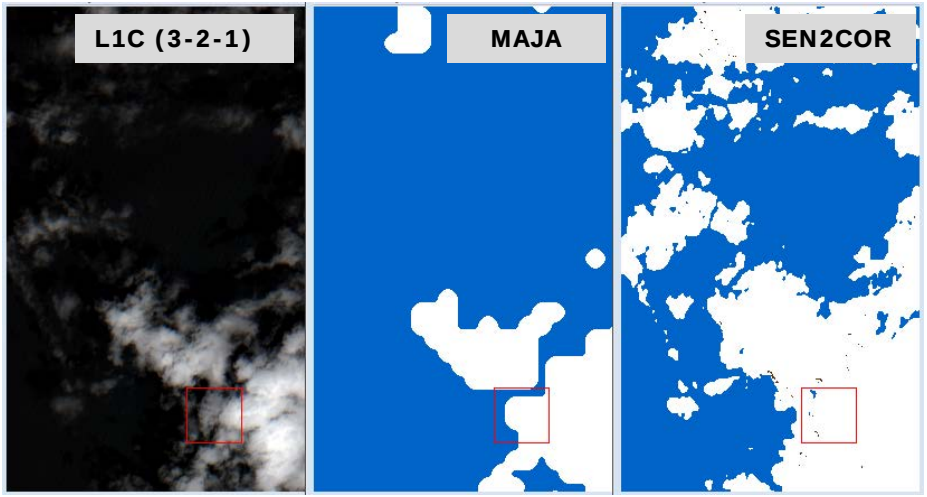


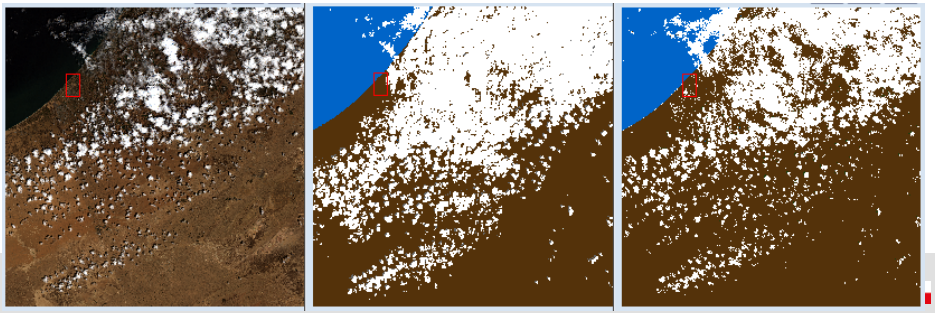
- Which spatial resolution is needed for users own applications?
- MAJA snow mask is only indicative (other snow product by CNES available)

Quarzazate (Morocco) 17.04.2016;
L1C_T29RPQ_A004281_20160417T111159

4. Validation Examples







- Large amount of false clouds detected by Sen2Cor in bright and urban areas
- Omission of clouds over water by MAJA

Sede Boker (Israel) 06.05.2016; L1C_T36RXV_A004551_20160506T083117

5. Conclusions

- MAJA and Sen2Cor provide **high quality cloud masks** – both products are freely available and users are invited to test and compare those on own test-sites!
- **Thin cirrus cloud** definition and labeling is **challenging**
- Both processors are less accurate in cloud shadows and topographic shadows classification
- Advantage of MAJA multi-temporal algorithm, particularly for arid and semi-arid locations

  Zupanc et al.: MAJA outperforms single-scene algorithms in terms of land misclassification as clouds; Very bright surfaces are problematic for Sen2Cor
- Disadvantage of MAJA concerning low spatial resolution of masking (pixel + dilation=480m)
- Sen2Cor could perform still better if dilation of cloud mask would be applied (planned in the following versions)
- Building a representative reference data set is a huge work … **validation protocol for L2A to assure validation quality needed.**

Many thanks for your attention

References
•Hagolle, O. et al. (in preparation), „Validation of Sentinel-2 cloud masks obtained from MAJA software and comparison with Sen2cor cloud masks”
• Louis, J., et al. (2017), „Evolutions of Cloud Screening and Scene Classification in Level-2A atmospheric correction processor Sen2Cor”, RAQRS V Symposium, 18.-22.Sep. 2017, Valencia.
•Zupanc, A. et al. (2017), „Improving Cloud Detection with Machine Learning” (available: https://medium.com/sentinel-hub/improving-cloud-detection-with-machine-learning-c09dc5d7cf13)