L2A Feasibility Study
MAJA V0 first delivery

ref : MAJA-TN-WP1-002 V1.0 2016/06/05

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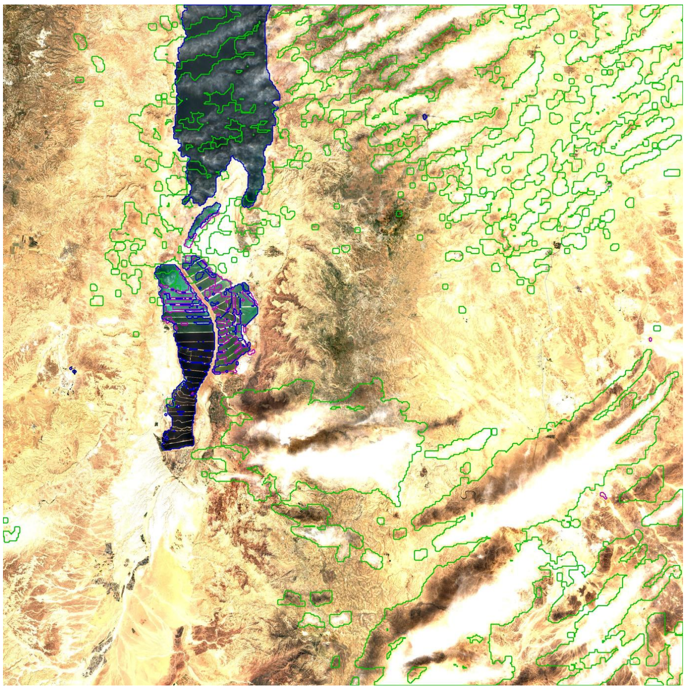

1 Purpose

This document briefly describes the first delivery of Sentinel-2 L2A products processed with MAJA V0. The references of the selected images are provided on Table 1, and their URLs on table 2.

2 Data set

4 sites have been selected by ESA for this first delivery (one of which, Neguev, is a "backup site"), only one date and 4 tiles were processed for each site. The table 1 provides all the necessary information to access the data.

Table 1: Characteristics of the selected images

site	Tiles	Orbit	date
LaCrau (France)	31TFJ, 31TGJ, 31TGK, 31TFK	108	2016-03-26
Atlas (Morocco)	29RPQ, 29RNQ, 29SNR, 29SPR	137	2016-04-07
Pretoria(Sth Africa)	35JNM, 35JPM, 35JNN, 35JPN	135	2016-04-07
Neguev (Israel)	36RXV, 36RYV, 36RXU, 36RYU	121	2016-04-07

The level 1C data may be downloaded from the PEPS collaborative ground segment using the urls provided in table 2.

Table 2: URLs to access the L1C

site	URL
LaCrau	https://peps.cnes.fr/rocket//collections/S2/3d303ee0-0b93-5b4b-be95-2ca334f4e927
Atlas	https://peps.cnes.fr/rocket//collections/S2/8ae09aa2-dd67-5596-a0e1-ec2b9d912832
Pretoria	https://peps.cnes.fr/rocket//collections/S2/375b08ae-daeb-532f-bc4d-a33521e6ab9e
Neguev	https://peps.cnes.fr/rocket//collections/S2/04746365-b4e9-508d-bac0-ec151d3a52a4

As MAJA software uses multi-temporal criteria to enhance cloud detection and aerosol estimates, we did not only processed the above mentionned dates, but we had to process the whole time series acquired between the 1st of December and mid of April. As a consequence, some of the validation results presented here will be based on the whole time series, to provide more significant statistics.

We encountered several difficulties related to the quality of Sentinel-2 products within the early stages of the ramp-up phase. On each of the time series, there are several products missing which were not acquired by Sentinel-2 or not produced by the ground segment to L1C. And among the remaining products, some are affected by incomplete information regarding the viewing angles, and therefore were not processed by MAJA. The available dates are available on the tables below.

This may have had some impact on the quality of the cloud detection and atmospheric correction which both improve when the acquisitions are frequent. In this case we were quite far from the nominal situation expected from a complete Sentinel-2 system with 2 satellites, however, MAJA still managed to provide correct results although not as good as they could have been.

Table 3: available data for La Crau

date	product reference	Quality
05/04/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160407T054600_R108_V20160405T103019_20160405T103019	OK
26/03/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160330T050601_R108_V20160326T103406_20160326T103406	OK
16/03/2016	Unavailable on Scihub	
06/03/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160308T091409_R108_V20160306T103024_20160306T103813	BadAngles
25/02/2016	Unavailable on Scihub	
15/02/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160215T212244_R108_V20160215T103211_20160215T103211	OK
05/02/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160210T111540_R108_V20160205T103556_20160205T103556	OK
26/01/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160128T091958_R108_V20160126T104630_20160126T104630	OK
16/01/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160117T021839_R108_V20160116T104056_20160116T104056	OK
06/01/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160106T212840_R108_V20160106T103956_20160106T103956	OK
27/12/2015	S2A_OPER_PRD_MSIL1C_PDMC_20151228T100614_R108_V20151227T104738_20151227T104738	OK
17/12/2015	S2A_OPER_PRD_MSIL1C_PDMC_20151217T195415_R108_V20151217T103953_20151217T103953	OK
07/12/2015	S2A_OPER_PRD_MSIL1C_PDMC_20151207T202356_R108_V20151207T104805_20151207T104805	OK

Table 4: available data for Atlas

date	product reference	Quality
17/04/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160417T133352_R135_V20160417T081407_20160417T081407	OK
07/04/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160408T045608_R135_V20160407T081351_20160407T081351	OK
28/03/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160331T102627_R135_V20160328T080803_20160328T080803	OK
18/03/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160318T192003_R135_V20160318T080751_20160318T080751	OK
08/03/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160309T070540_R135_V20160308T081127_20160308T081127	OK
27/02/2016	Unavailable on Scihub	
17/02/2016	Unavailable on Scihub	
07/02/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160207T232752_R135_V20160207T081608_20160207T081608	BadAngles
28/01/2016	Unavailable on Scihub	
18/01/2016	Unavailable on Scihub	
08/01/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160108T173140_R135_V20160108T082023_20160108T082023	OK
29/12/2015	S2A_OPER_PRD_MSIL1C_PDMC_20151229T150231_R135_V20151229T082023_20151229T082023	OK
19/12/2015	S2A_OPER_PRD_MSIL1C_PDMC_20151219T151201_R135_V20151219T082024_20151219T082024	OK

Table 5: available data for Pretoria

date	product reference	Quality
17/04/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160417T203056_R137_V20160417T111159_20160417T111159	OK
07/04/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160408T074439_R137_V20160407T111223_20160407T111223	OK
28/03/2016	Unavailable on scihub	
18/03/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160319T000701_R137_V20160318T112145_20160318T112145	OK
08/03/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160309T104548_R137_V20160308T112023_20160308T112023	BadAngles
27/02/2016	Unavailable on scihub	
17/02/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160217T214745_R137_V20160217T111843_20160217T111843	OK
07/02/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160207T192452_R137_V20160207T112209_20160207T112209	OK
28/01/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160128T212726_R137_V20160128T112006_20160128T112006	BadAngles
18/01/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160119T093732_R137_V20160118T113008_20160118T113008	OK
08/01/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160108T173633_R137_V20160108T112432_20160108T112432	OK
29/12/2015	S2A_OPER_PRD_MSIL1C_PDMC_20151229T201700_R137_V20151229T112948_20151229T112948	OK
19/12/2015	S2A_OPER_PRD_MSIL1C_PDMC_20151222T122148_R137_V20151219T113012_20151219T113012	OK
09/12/2015	S2A_OPER_PRD_MSIL1C_PDMC_20151211T090848_R137_V20151209T112253_20151209T112253	OK

3 Processing :

For this delivery, two versions of the L2A products are delivered :

- V0-A : the first data set was produced with MAJA V0 software, which corresponds to MACCS 4.8. The processing was done within the operational platform of CNES, MUSCATE.
- V0-B : the second data set was preprocessed at DLR to apply the cirrus and haze removal methods included in ATCOR. New "haze and cirrus free" L1C products were generated which were then transferred to CNES to undergo the same processing as above. This second version is somewhat experimental as it was only done, for the first time, a few days between the V0 delivery date, and underwent very little validation.

Moreover, for both versions, we deliver two steps of the atmospheric correction :

- The files marked with "SRE" (for Surface REflectance) are atmospherically corrected images, taking into account adjacency effects
- The files marked with "FRE" (for Flat surface REflectance) underwent the same processes as "SRE" images, plus a correction for illumination variations due to topography. The images look like if the terrain was flat, as may be seen on Fig 1 which looks like flat despite altitude variations around 4000m due to the Atlas mountains.

Every site, every tile within each site, and every date within the available dates (marked with OK in the above tables) where processed with identical parameters, thresholds, and aerosol models. These parameters were not tuned specifically for this experiment but are identical, *mutatis mutandis*, to the parameters used for THEIA's production of SPOT (Take5) and LANDSAT 8.

For a given site, the 4 tiles were also processed independently. One special feature of MACCS, which may be changed easily if needed, is that MACCS does not issue a L2A for a tile which has more than 90% of clouds. With such an amount of clouds, the remaining pixels are not always well classified, and this feature enables to save time and data volume. In the pretoria image, for this reason, one of the tiles is not produced.

Table 6: available data for Neguev

date	product reference	Quality
06/04/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160407T213245_R121_V20160406T083051_20160406T083051	OK
27/03/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160330T140603_R121_V20160327T082559_20160327T082559	OK
17/03/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160317T130014_R121_V20160317T082111_20160317T082111	BadAngles
07/03/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160309T010805_R121_V20160307T082908_20160307T082908	OK
26/02/2016	Not available on Scihub	
16/02/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160216T151629_R121_V20160216T082059_20160216T082059	BadAngles
06/02/2016	Not available on Scihub	
27/01/2016	Not available on Scihub	
17/01/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160119T032918_R121_V20160117T083220_20160117T083220	OK
07/01/2016	S2A_OPER_PRD_MSIL1C_PDMC_20160107T183056_R121_V20160107T083407_20160107T083407	OK
28/12/2015	S2A_OPER_PRD_MSIL1C_PDMC_20151228T171200_R121_V20151228T083611_20151228T083611	OK
18/12/2015	S2A_OPER_PRD_MSIL1C_PDMC_20151218T151838_R121_V20151218T083345_20151218T083345	OK
08/12/2015	S2A_OPER_PRD_MSIL1C_PDMC_20151208T155737_R121_V20151208T083248_20151208T083248	OK

4 Product format

Due to the very tight schedule for the V0 delivery, the products are delivered with our ground segment product format, which is based on geotiff. The data format is accurately described here :

RD1	SENTINEL-2A L2A Products description	MAJA-TN-WP1-002

5 Validation

Despite the very tight schedule, a few validations were processed :

- visual check of cloud masks
- consistency check of the 4 tiles of a given image
- validation of estimates of water vapour and aerosol optical thickness with regard to Aeronet in-situ measurements

5.1 Visual check of cloud masks

MACCS performs the detection of clouds/cloud shadows, water and snow at a reduced resolution, here 240m, in order to save time and also avoid false detections that could occur at full resolution. The clouds masks are also dilated because it has been observed that the edges of most clouds are fuzzy, and also because adjacency effects due to clouds cannot be accurately corrected in their neighborhood.

On the image of one of Atlas site tiles (T29RNQ) displayed on figure 1, we circled the detected cloud/shadows in green, the detected water in blue and the detected snow in pink. Here is some of the comments we may draw from the analysis of the images :

- The detection of clouds either cumulus near the Atlas mountain, or thin clouds in the North East is accurate. False detections are very scarce, except where a partial snow cover is sometimes classified as clouds.
- One cloud detection in the North west of the image is also doubtful. Water and full snow cover are very well detected. On the image of one of Neguev site tiles (T36RYV) displayed on figure 2, several types of thin clouds may be seen. All of them are very well detected despite the very bright landscape. Their shadows are also mostly well detected, even if a some of them escape the detection in the Northern parts of the image. In this V0 processing, we used the version 4.8 of MACCS, but the version 5.0 was just delivered and will be used for the V1 production at T0+6. When applied to SPOT5 (Take5), this new version deeply enhanced the results (see the blog post `http://www.cesbio.ups-tlse.fr/multitemp/?p=7227`). The water mask is not perfect, as some very turbid and salty waters are classified as snow, due to the high reflectance in the visible and the very low reflectance in the SWIR.
- On the LaCrau site (Tile T31TFJ), the same phenomenon can be observed (Fig. 3), with some salty and turbid water bodies escaping the water mask. The cloud detection is excellent, and the only exception is the snow on the Mont Ventoux, which is partially classified as cloud.

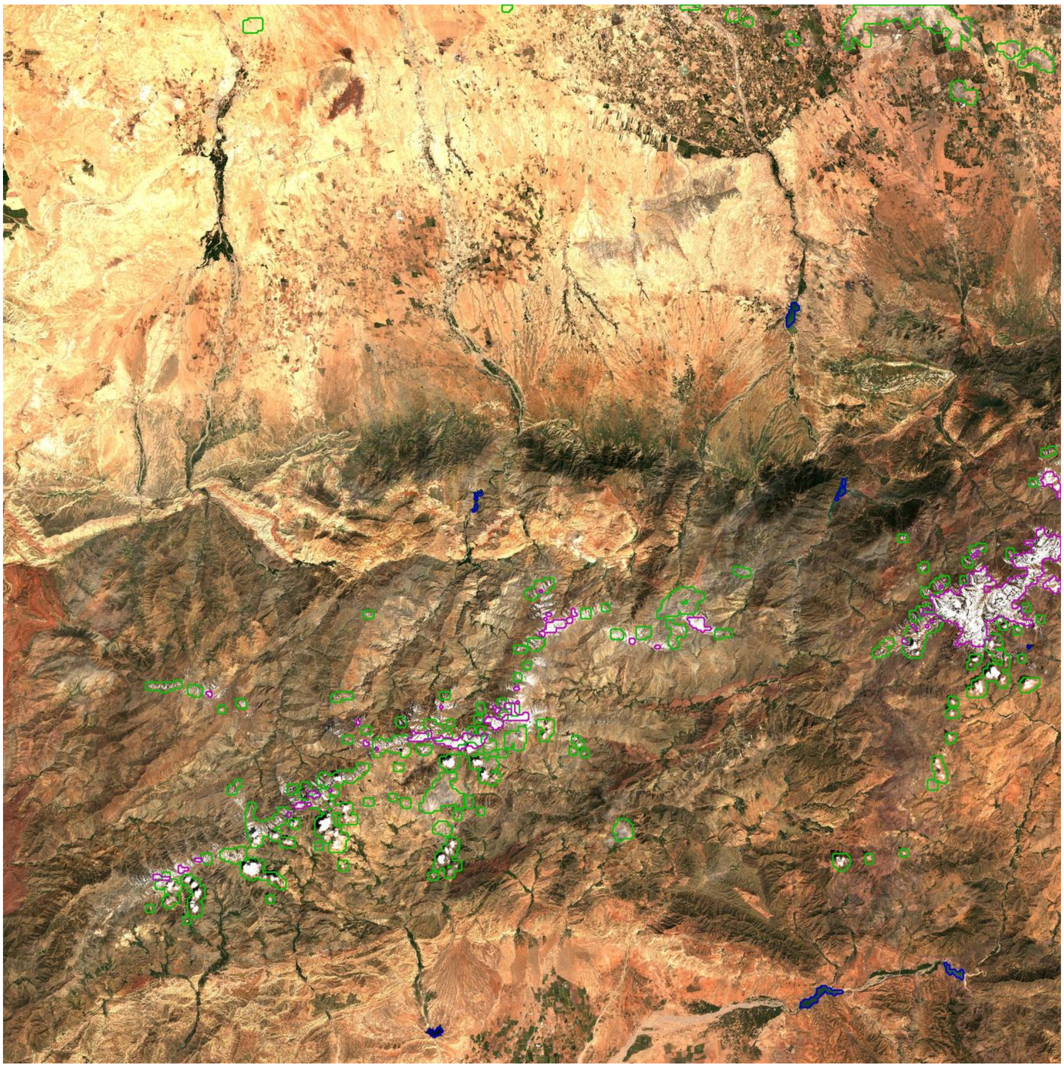

Figure 1: Example of quicklook for cloud mask visual control for Atlas site, cloud and shadows are circled in green, water in blue and snow in pink

- Finally, the cloud mask obtained on Pretoria (T35JPM) is also very accurate (Fig. 4), even if it forgot a few very small clouds (beware, all the white dots are not clouds, there are some mines and some greenhouses). MAJA V0 cloud masks were processed at a resolution of 240 m, but this resolution is only a parameter. We do not not advised to run the cloud detection at full resolution to avoid commission errors, and the chosen resolution is in fact a compromise between accuracy and computing time : it could be reviewed depending on the computing power allocated to the Level2A processing. For SPOT5 (Take5) experiment, a resolution of 100 m of 100m was used, which provided better results, but the amount of data and data volume was low compared to Sentinel-2. And finally, to run MACCS with a higher coarse resolution will require a better multi-temporal image registration than the performance available during the ramp-up phase.

5.2 Consistency checks of the different tiles

The figures 5 to 8 show brute force mosaics of the tiles generated using *gdal_merge.py* function which makes very simple mosaics : the successive images in the command line are merely overlaid on the previous ones. The four images produced this way do not show any artifact along the seamlines, showing that although the tiles are created independently, the processing stays consistent across the tiles. Just to show how the artifacts could look like, the Figure 9 shows what could happen in the case of differences of atmospheric correction among the tiles. It was generated with sen2cor V2.2.1 with the standard correction parameters, but we might have done something wrong, being not experts in the use of Sen2Cor.

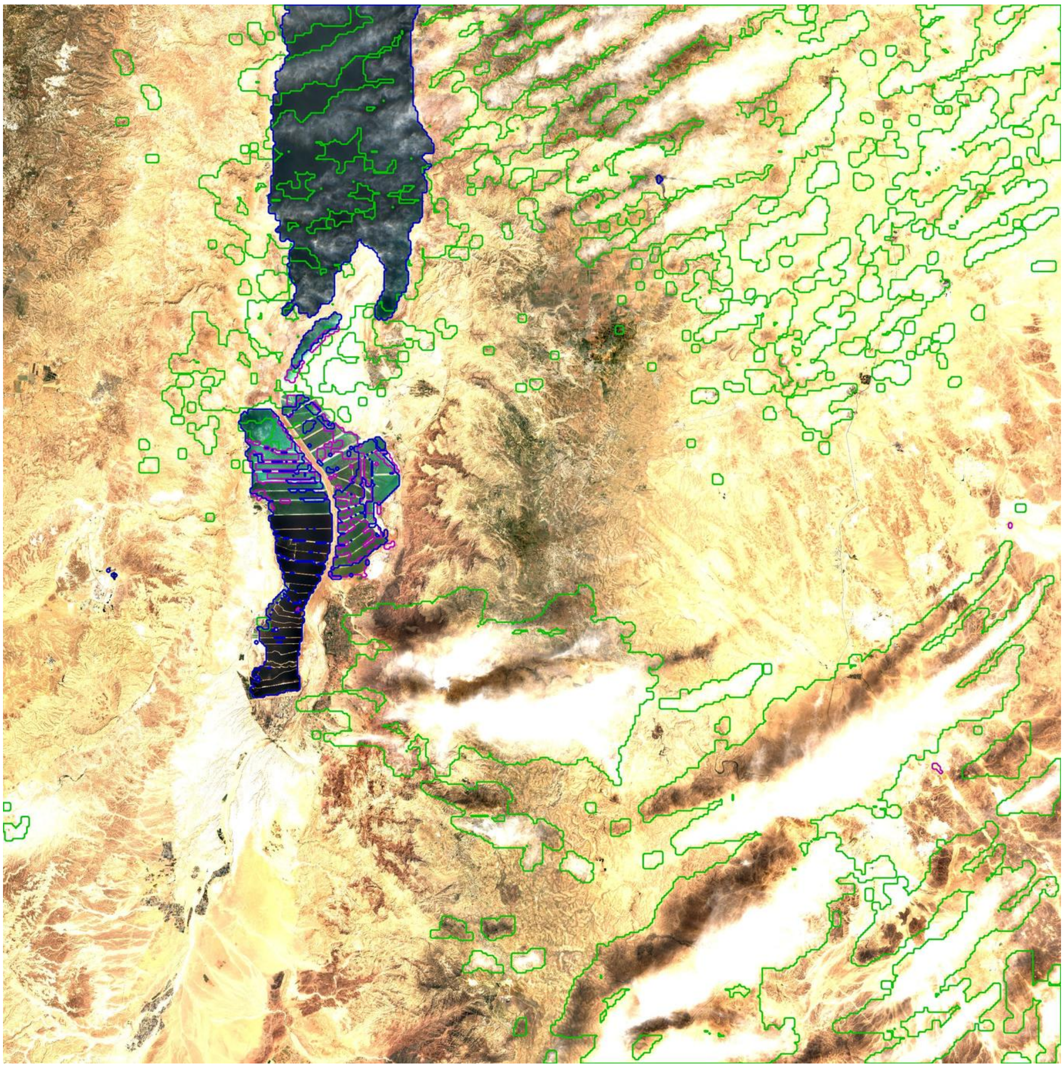

Figure 2: Example of quicklook for cloud mask visual control, for Neguev, cloud and shadows are circled in green, water in blue and snow in pink

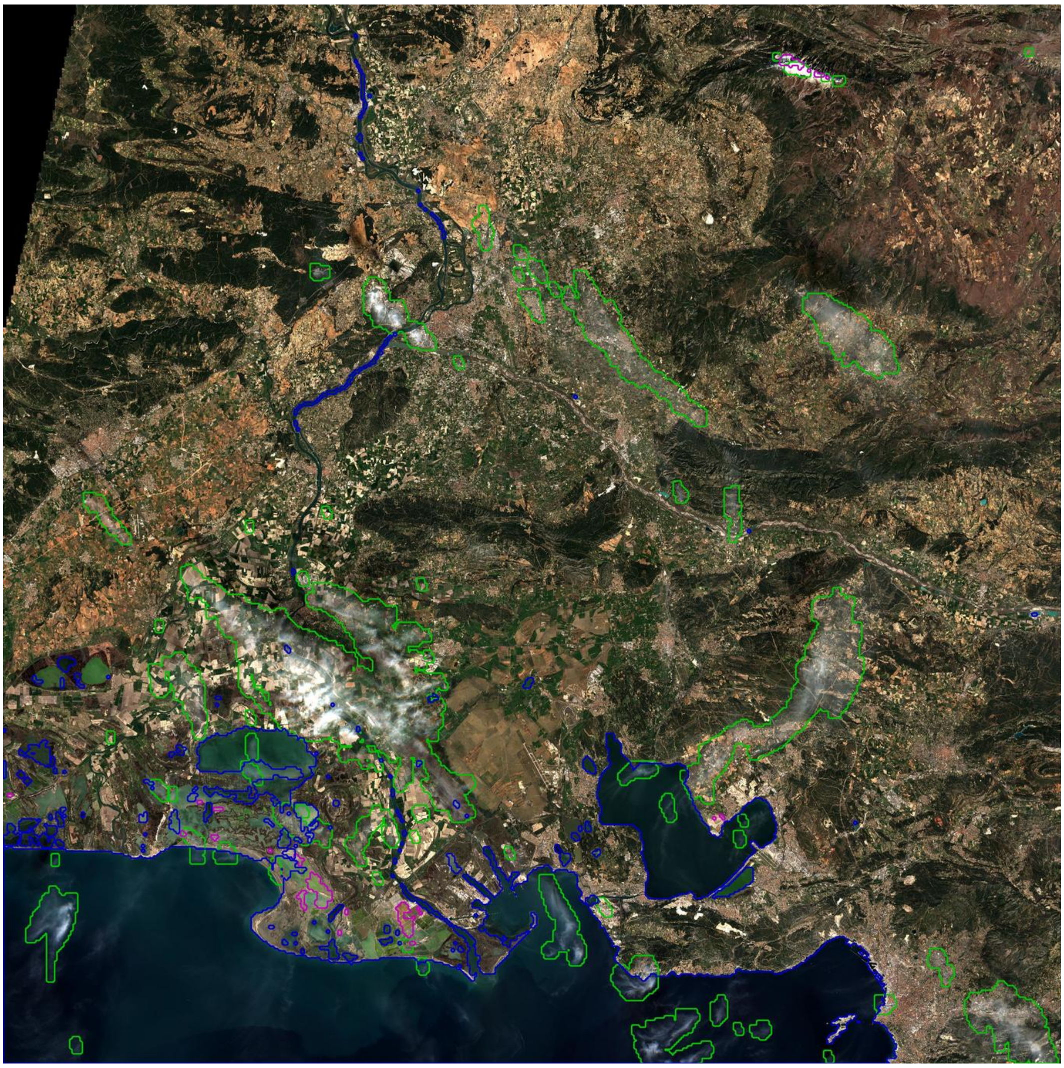

Figure 3: Example of quicklook for cloud mask visual control, for La Crau, cloud and shadows are circled in green, water in blue and snow in pink

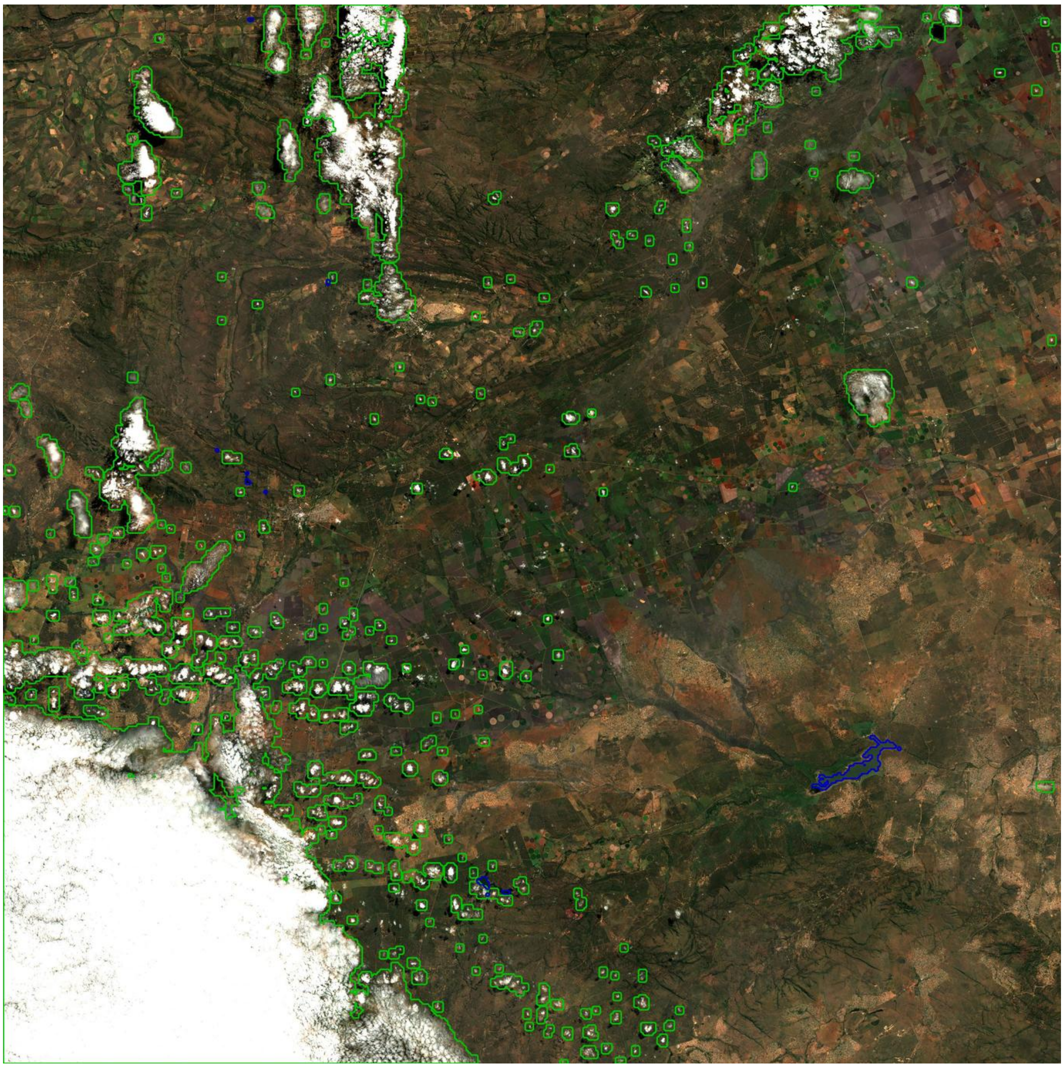

Figure 4: Example of quicklook for cloud mask visual control, for Pretoria, cloud and shadows are circled in green, water in blue and snow in pink

Figure 5: Mosaic of the 4 tiles of Atlas

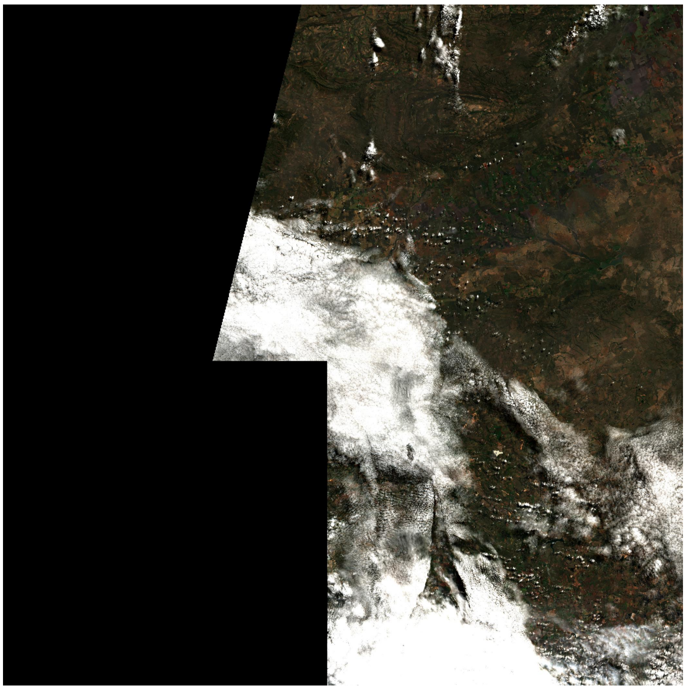

Figure 6: Mosaic of the 4 tiles of Pretoria. One tile was not issued because fully cloudy

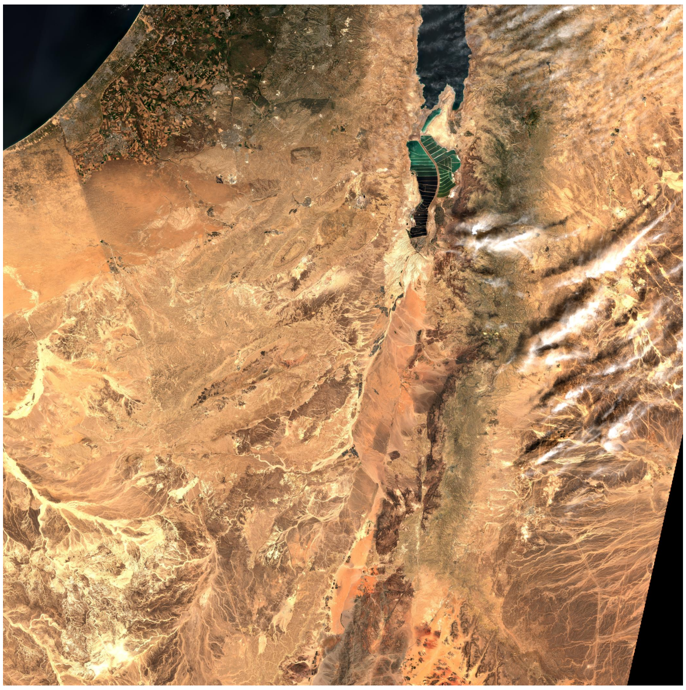

Figure 7: Mosaic of the 4 tiles of Neguev

Figure 8: Mosaic of the 4 tiles of La Crau

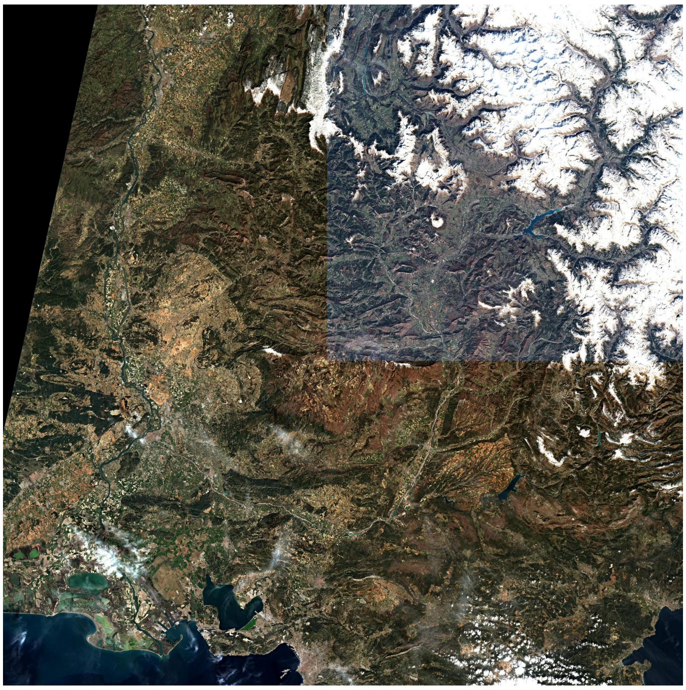

Figure 9: Mosaic of 4 tiles generated with Sen2cor (V2.2.1)

5.3 Aerosol and water vapour validation

As the quality of atmospheric correction strongly depends on the estimates of aerosol optical properties, one good way to validate is to use in-situ measurements of aerosol optical thickness (AOT).

A study done by CNES concluded on the selection criteria to apply to the in-situ data and image data to select reliable match-ups :

- compare the AOT obtained from the in-situ data, with the average AOT obtained within 10 km of the Aeronet Sunphotometer
- no cloud/cloud shadow (less than 20%) in the neighbourhood of the in situ measurement
- Stability of AOT with time in in-situ data (less than 0.03 in AOT variation within one hour)
- aeronet data with at least 2.0 level (cloud screened)

This criteria correspond to the blue dots in the provided graphs (Figure 10).
In order to gain more statistics, we released a few conditions and showed them with red dots.

- no cloud/cloud shadow (less than 60%) in the neighbourhood of the in situ measurement
- aeronet data with at least 1.5 level (cloud screened)

Aeronet in-situ measurements can also be used to measure water vapour and validate the estimates that come from Sentinel-2 water vapor band (VAP).

In both cases, special attention will have to be paid to sites in rugged terrain, as the AOT and moreover water vapour are dependent on altitude. In our validations of water vapour we figured out that a 2x2 km neighborhood was sufficient, contrarily to AOT where a 10*10 km neighborhood is better.

Based on this, an operational validation has been set-up, which can systematically process the data produced by MAJA within MUSCATE, find the matchups with Aeronet and deliver the plots.

As all the sites have at least one or two sun-photometers, we were able to derive a validation of the AOT and VAP. The results are plotted on Figure 10. These results are rather decent for AOT and quite good for water vapour, taking into account that :

- some of the sites (Sde Boker (Neguev), Ouarzazate (Atlas)) are very bright, and estimating the AOT above bright zones is difficult, and some DDV methods might not be able to perform the estimates because of the lack of dark pixels.

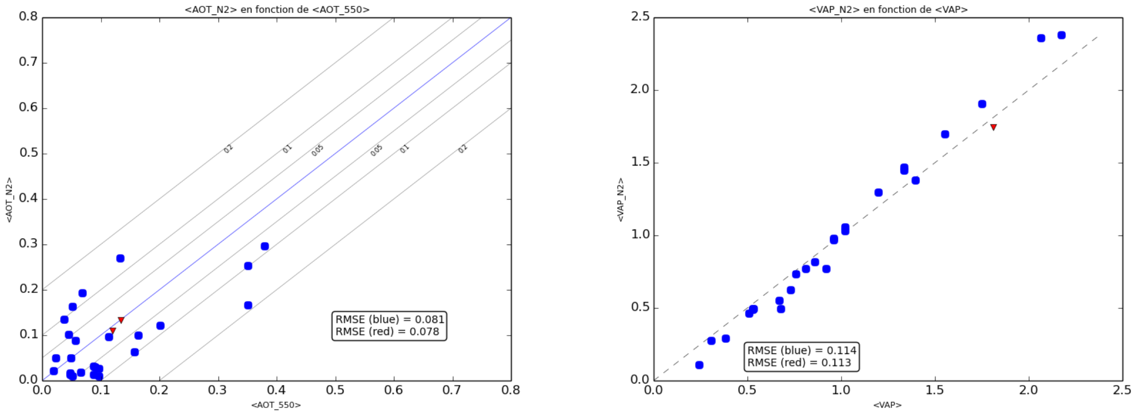

Figure 10: Validation of AOT(left) and water vapour (right) estimated by MAJA V0 compared to Aeronet in-situ measurements, using all sites and all dates processed. Blue dots correspond to the best matchup-conditions, red to less strict match-up conditions)

- the repetitivity of observations is not what it should be, and very large data gaps (40 to 50 days) were observed, which is not ideal for a multi-temporal method, and is not representative of the actual situations that should be observed with Sentinel-2 operational system.
- the tuning of DDV coefficients for Sentinel-2 (we used the coefficients tailored for LANDSAT 8 spectral bands) will be refined during this study
- the water vapour estimation method in MAJA V0 originates from a very simple method implemented within MACCS. In the framework of this feasibility study, a more elaborate method from DLR will be tested : if it provides better results than the current method, which is likely, it will be implemented within MACCS.

5.4 Comparison of V0-A and V0-B products with haze/cirrus removal

As said above, for this V0 version, the integration of haze and cirrus removal was performed as an independent pre-processing before MACCS processing. Figures 11 and 12 compare the images obtained above two of the sites with and without cirrus/haze correction. The cirrus correction performed on the image of La Crau is really impressive, even where the cirrus clouds are thickest. These parts of the images which were unusable become now perfectly usable. On the second image, one of the drawbacks of the method arises, as the brightest parts of the desert are also corrected (we checked that the bright zones also appear on the previous S2 image and are not clouds or haze).

This quite brutal merge of MACCS and ATCOR corrections will need polishing, but it still shows the large potential of the cirrus and haze correction, and the benefit of merging both methods. We could for instance apply this correction only to the pixels detected as clouds by MAJA (with some smoothing to avoid artefacts at the edges of the cloud). The merge of both methods will be studied in the next months in the framework of this study.

6 Conclusions

Due to several reasons, the images presented here show results where the MAJA processor is not at its best, compared to what it will provide when Sentinel-2 is in nominal configuration with 2 satellites. Not only we only have one satellite, but moreover, the acquisition rhythm is not steady yet and the ground segment sometimes failed delivering products conform to their requirements.

Despite this situation, MAJA succeeded in providing decent quality L2A products, showing its robustness to degraded conditions, with a choice of difficult sites, including two very bright sites, Atlas and Neguev. Its ability to perform in an operational production environment was also demonstrated, as a total of 40 images have been processed in less than a day.

The inclusion of several enhancements developed in the framework of the feasibility, such as the new cloud shadow detection method, or haze and cirrus correction, and the tuning and validation of several parameters performed during this feasibility study should provide even better results soon. The simple test of a pre-processing to remove haze and cirrus clouds also showed very promising results, and by a better integration of both codes, we should get the pros and avoid the cons of this method.

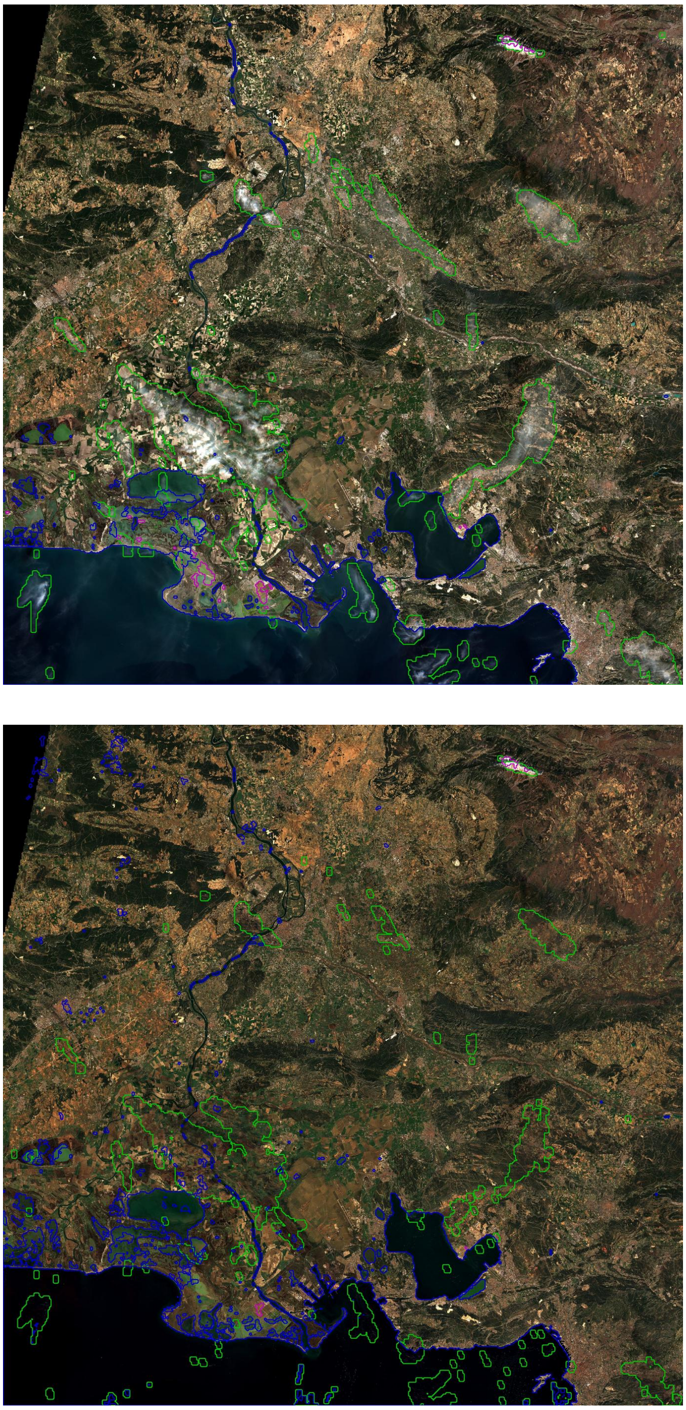

Figure 11: Comparison of V0-A (top) and V0-B (Bottom) with correction of haze and cirrus, for LaCrau

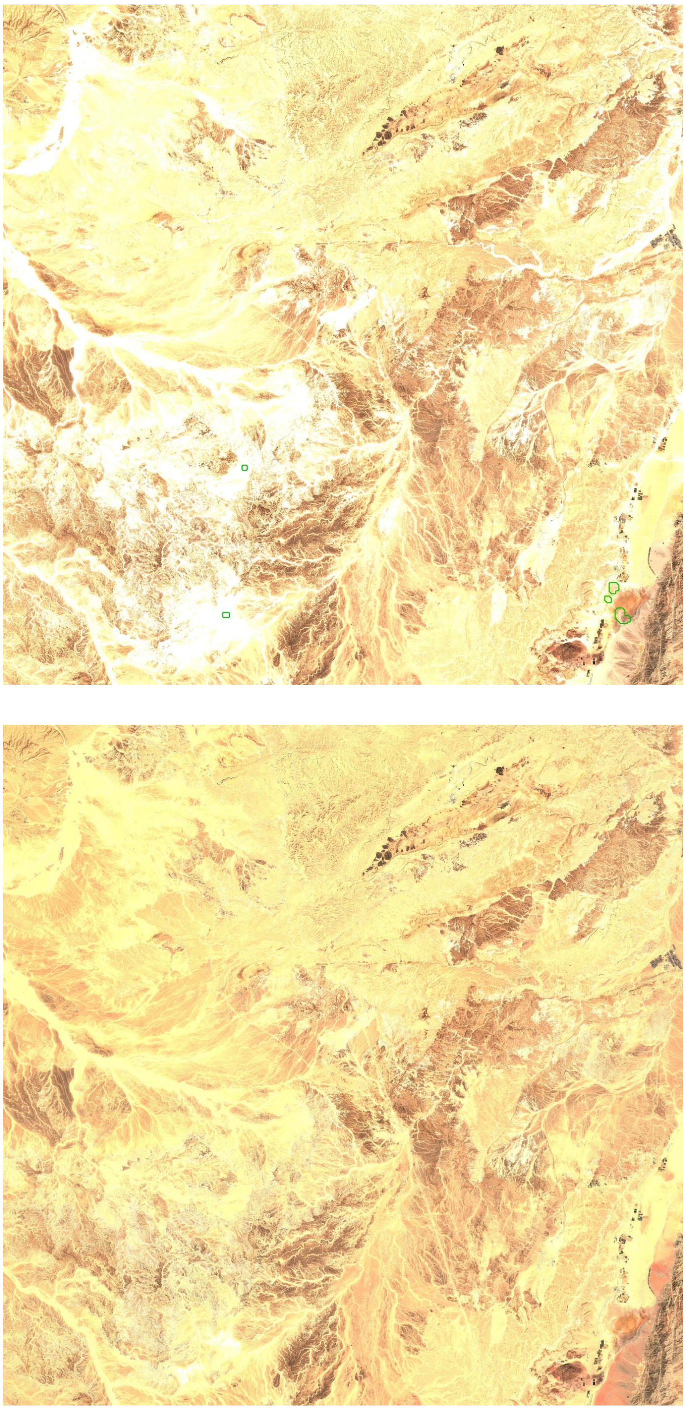

Figure 12: Comparison of V0-A (top) and V0-B (Bottom) with correction of haze and cirrus, for Neguev

7 References

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8 Acknowledgement

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