S2 MPC

Multi-Layer Copernicus Sentinel-2 GRI in Level-1B - Product Handbook

Ref. S2-MPC_PHB_MultiLayer_L1B_GRI

The power of innovation

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Table of contents

1. INTRODUCTION 5
1.1 Purpose of the document 5
1.2 Document structure 5
1.3 References 5
1.4 Terminology 6
2. PRODUCT SPECIFICATION 7
2.1 Definition 7
2.2 Accuracy 7
2.3 Multi-temporal registration 7
2.4 Coverage 8
2.5 Cloud rate 8
3. PRODUCT GENERATION AND EDITING PROCESS 9
3.1 From a continental to a global GRI 9
3.2 How the GRI was build 10
3.2.1 Data selection 10
3.2.2 Data Refining 11
3.2.2.1 Creation of a block 11
3.2.2.2 Choice of the unknowns 11
3.2.2.3 Tie points 12
3.2.2.4 Ground Control Points 13
3.2.2.5 Refining 13
3.2.2.6 Internal validation 14
3.2.3 External Validation 16
4. PRODUCT QUALITY PERFORMANCE 17
4.1 Geographic coverage 17
4.2 Coverage by orbit 17
4.2.1 Orbit R109 18
4.2.2 Greenland & Northern Canada 18
4.3 Overlap 18
4.4 Known issues or supposed weaknesses 19
4.4.1 Lack of GCPs 19
4.4.2 Missing detectors 20
4.5 Absolute geolocation performance of the GRI 20
4.6 Relative coherence 21
4.6.1 General results 21
4.6.2 Limits of the analysis 22
4.6.3 More interpretable information 22
5. PRODUCT FORMAT 24
5.1 High-Level Structure 24
5.2 Product Structure / Naming Convention 25

5.2.1 GRI Orbit Directory Format 25
5.2.2 GRI Description File Format..25
5.2.3 Unitary Level-1B User Product Format 26
6. USER GUIDE 28
6.1 Use of the GRI by the Sentinel-2 Level-1 processor 28
6.1.1 Viewing model refining principle...28
6.1.2 Ground Control Points Selection in Sentinel-2 Level 1 processor ...29
6.1.2.1 GRI Products Selection 29
6.1.2.2 Common geometry resampling 29
6.1.2.3 GCP Collection 30
6.1.2.4 Spatio-triangulation 31
6.2 Use of the Multi-Layer GRI for other missions 32
7. DISTRIBUTION, LICENSE, AND COPYRIGHT 34
7.1 Distribution.. 34
7.1.1 Distribution website 34
7.1.2 Distribution format...34
7.2 License and copyright 34

1. Introduction

1.1 Purpose of the document

This Product Handbook aims at providing in a unique document, all the information regarding the generation and the use of the Sentinel-2 Multi-Layer Global Reference Image (GRI) in Level 1B format.

Please note that the GRI product and related documentation are full, free and open for the international users.

1.2 Document structure

The Product Handbook contains the following chapters:

- ✓ "Product Specifications" chapter that describes the detailed L1B multi-layer GRI accuracy, multi-temporal registration, its coverage, and residual cloud rate.
- ✓ "Product Generation and Editing Process" chapter that describes how the Multi-Layer L1B GRI has been built,
- ✓ "Product Quality Performance" chapter that provides a high-level quality information of the GRI on the geolocation performance, strengths and weaknesses.
- ✓ "Product Format" chapter that describes the GRI structure and the naming convention,
- ✓ "User Guide" chapter that describes some use cases of the Multi-Layer L1B GRI,
- ✓ "Distribution, License, and Copyrights" chapter that gives some information on the distribution of the GRI (where to find it, license, and copyrights).

1.3 References

Id	Title	Reference
[VAL-ML-L1B-GRI]	Sentinel-2 Multi-Layer L1B GRI Validation Report	S2-MPC_VAL_MultiLayer_L1B_GRI, V1
[S2-L1-ATBD]	Sentinel-2 Level-1 ATBD	S2-PDGS-MPC_ATBD-L1, V1.0
[S2-PSD]	Sentinel-2 Product Specification Document	S2-PDGS-TAS-DI-PSD, 14.9
[PHB-L1B-L1C-GCP-GRI]	Sentinel-2 L1B & L1C GCP GRI Product Handbook	S2-MPC_PHB_ L1B_L1C_GCP_GRI, V1

All the above documents are available on Sentinel Online website in the Sentinel 2 Document Library: https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/document-library.

1.4 Terminology

Datastrip	Within a given Sentinel-2 Datatake, a portion of sensed image downlinked during a pass to a given station is termed Datastrip. If a particular orbit is acquired by more than one station, a Datatake is composed of one or more Datastrips (for more details see [S2-PSD])
Datatake	Continuous acquisition of an image from one Sentinel-2 satellite in a given MSI imaging mode (for more details see [S2-PSD])
Granule	Minimum indivisible partition of a product (containing all possible spectral bands). For Level-1B, granules are sub-images of a detector with a given number of lines along track. A granule covers approximately 25 km across-track and 23 km along-track (for more details see [S2-PSD])
PDI (Product Data Item)	Physical Sentinel-2 product components corresponding to the minimum indivisible partition of one Sentinel-2 User Product (for more details see [S2-PSD])
Quicklook (QL)	Rapidly produced satellite image without special correction for determining cloud cover
SAFE	Standard Archive Format for Europe [1]
User product	A Sentinel-2 User Product is defined by a collection of data items (image, ancillary, auxiliary data) and metadata describing all elements composing the product (for more details see [S2-PSD])

[1] https://earth.esa.int/eogateway/activities/safe-the-standard-archive-format-for-europe

2. Product Specification

The Multi-layer L1B GRI has been created as an auxiliary data to be used by the Sentinel-2 operational processor to improve the geometric performance of Sentinel-2 products.

The geometric refinement algorithm based on the GRI was introduced in operations since 30th of March 2021 over the Euro-Africa region and then the 23rd of August 2021 worldwide. Subsequently, both absolute geolocation and relative (multi-temporal) performances have significantly improved and meet the Mission Requirements.

2.1 Definition

The GRI is defined as a global, as cloud free as possible, mono spectral (band B04, red channel) and properly geolocated set of L1B images so as to fulfil the following L1C requirements:

- ✓ 12.50 m CE95 at L1C (L1B images are refined on the GRI)
- ✓ Multi temporal registration of 0.5 pixels @ 95%

2.2 Accuracy

The needed accuracy on the GRI shall lay upon the two following main factors:

- ✓ the capability of the refining algorithm to match with the GRI,
- ✓ the accuracy of the DEM, at orthorectification step.

A preliminary study made by CNES in 2014 based on budget error analysis ([GS2-TN-SY-1349-CNES]), showed that 9.00 m CE95 is required on the GRI. This value is based on budgets estimations, taking into account the capability of the refining algorithm to match with the GRI (0.5 pixel) and the DEM accuracy requirement is 16 meters. The overall accuracy of the Copernicus DEM is better than that.

2.3 Multi-temporal registration

The requirement of 0.5 p @95% for the multi temporal registration at Level-1C has been defined and tested for images along the same repetitive relative orbits and is quite ambitious. For neighbouring orbits and especially over high latitudes, where there is a full overlap between relative orbits, reaching this requirement turns to be very hard, since issues due to DEM accuracy and different incidence angles are combined. To reach this requirement does not depend only on the accuracy of the GRI, but also on the efficiency of the refining process and the accuracy of the DEM used to product L1C images.

2.4 Coverage

A list of all territories to be covered by images from the Sentinel-2 mission was provided at the beginning of the project. It includes the mainlands and a long list of islands (see section 4.1 where the list of Islands is provided).

The goal is to get enough homologous points between the L1B products and the GRI during the refining step.

2.5 Cloud rate

The goal for the cloud free coverage requirement is to find enough points between the L1B image to refine and the GRI.

To limit the cloudy parts within the GRI, appropriate L1B products, as much as possible cloud free, are selected and only the cloud free areas are kept. Several images are superposed when needed so that the “addition” of the stack is cloud free enough.

The threshold of acceptability with regards to the cloud rate is that the GRI is considered cloud free enough and usable when at least 1 relevant point in an area of 300 km x 300 km can be found.

3. Product Generation and Editing Process

This section helps understanding how the multi-layer L1B GRI was built, and the technical choices made during its consolidation.

3.1 From a continental to a global GRI

The GRI was firstly created into separated continental blocks in order to build it progressively.

It is over Europe that the first GRI block was generated, and it has been achieved a few months after Sentinel-2A launch. The validation of this first European block confirmed a correct geolocation of the GRI and a correct functioning of the refining process within the ground processor. It was also shown that the multi temporal registration was reaching the expected target for products within the same orbit.

Then the blocks over the other continents were built up.

Working continent after continent allowed building up and making a validation of the GRI data progressively, without waiting for a worldwide coverage being available.

Finally, a global block has been computed by merging all continental blocks and other parts of the globe initially set aside: Siberia, North Canada, Greenland, other little islands and remaining holes.
All blocks had been carefully designed to ensure a sufficient overlap between continents, so that it was possible to compute tie points between products from adjacent blocks.

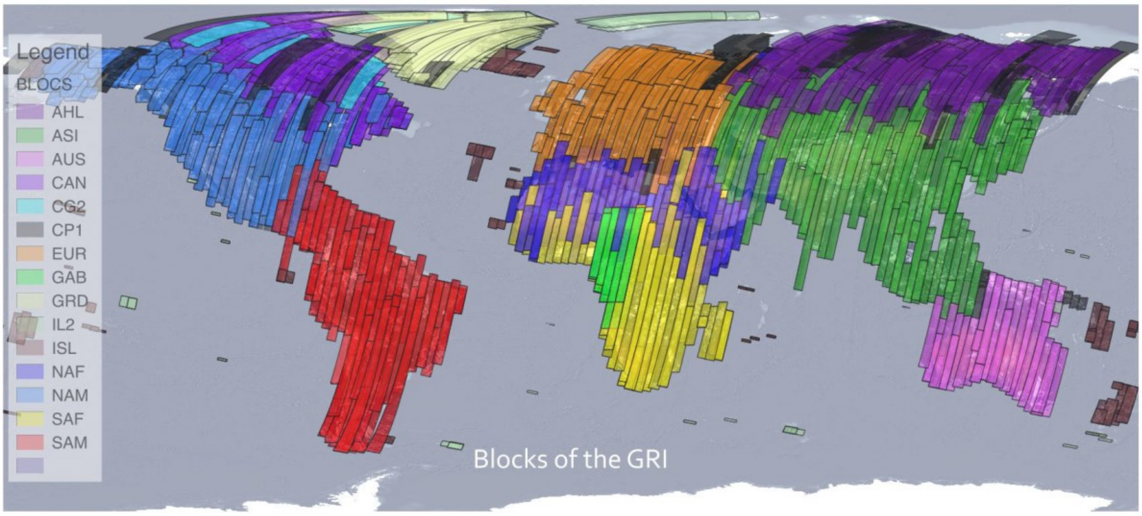

Figure 1: The blocks of the GRI

The merging gave the opportunity to better tune the parameters in view to the refining process.

The global block is refined at datastrip level, instead of at product level. It means that the unknowns (yaw, pitch & roll) are declared as independent within each datastrip. This implementation brings more flexibility for long products as illustrated below:

Figure 2: Refining at product level and datastrip level. To refine the datastrips brings more flexibility

3.2 How the GRI was build

This part of the document reminds the different steps of the method used to create the GRI.

3.2.1 Data selection

The selection of the L1B products was based on the visualisation of quicklook (QL) images at 320m of resolution. It consists in displaying the various available QL in overlap with a defined area (e.g. a continent), sorting them to achieve a cloud free cover after selecting only the useful part of the L1B image strips.

When no cloud free image was found, several images as much as possible cloud free, were selected and cut. Therefore, several images are superposed when needed so that the "addition" of the stack is cloud free enough and thus that the virtual mosaic shows an acceptable cloud cover rate for refining.

Consequently, in equatorial areas, the stack is in average more substantial than for the rest of the world.

Another constraint is also to keep a reasonable stack, to avoid a too long processing time for the refining algorithm.

3.2.2 Data Refining

3.2.2.1 Creation of a block

This step consisted in creating the block to refine.

A block can be defined as a set of images to refine. Each image has a set of unknowns to solve (here 7 by datastrip of each product). Some constraints and relations between the images (weights on the unknown, GCPs, tie points) are also added to the equation.

Once the unknowns were estimated, the block was refined.

3.2.2.2 Choice of the unknowns

The initial recommendation was to refine only yaw, pitch, roll and magnification.

Indeed:

- ✓ Pitch, translation along track and datation error are redundant,
- ✓ Roll and translation across track are redundant,
- ✓ Magnification effect and translation in Z are redundant.

On each parameter, a polynomial model is usually proposed.

For the GRI, it was decided to limit this model to an order 1, due to the length of L1B acquisitions. Indeed, proposing a 2nd degree polynomial in pitch for example on a strip of 4 000 km could lead to too severe corrections at the beginning and the end of the product. This explains why it was decided to limit the model to an order 1.

The table below reminds the order of magnitude of the correction for every parameter to be refined.

Table 1: Order of magnitude of the attitude of the satellite

$Pitch_0$ 1µrad ⇔ 0.7 m (on ground) (⇔Along track translation)	**$Pitch_1$** 1e-8 rad.s-1 ⇔ 1 m/1000 km of acquisition (⇔Along track drift)
$Roll_0$ 1µrad ⇔ 0.7 m (on ground) (⇔Across track translation)	**$Roll_1$** 1e-8 rad.s-1 ⇔ 1 m/1000 km of acquisition (⇔Across track drift)
Yaw_0 1µrad ⇔ 0.15 m (at swath border)	**Yaw_1** 1e-8 rad.s-1 ó 0.2 m/1000 km of acquisition (at swath border)
Magnification 1e-6 ⇔ 0.3 m (at swath border)	

Regarding these values, it was expected to find corrections values on ground around 10 meters (corresponding to the geolocation performance of Sentinel-2). Thus, weights were applied on the 7 unknowns by datatstrip, in order to obtain an on-ground correction of this order of magnitude. When finally, the applied corrections were bigger, it was considered as suspicious in the processing.


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        </Z>
    </Homothety>
</MSI_State>
```


Figure 3: Example of an applied correction within a product of the GRI

3.2.2.3 Tie points

The tie points selection was based on the spatio-triangulation method to ensure the relative coherence between images. They were computed using in-house developed software tools.

The first part of the process consisted of extracting everywhere in the image using the SURF (Speaded Up Robust Features) algorithm [2]. These points of interest were selected automatically according to the local image texture and then correlated with all the images in overlap. At this step, a filtering relying upon the correlation coefficient was performed.

The results obtained after this fully automated phase were almost fully satisfactory since less than 3% of the points are filtered at a later stage (spatiotriangulation). In other words, 97% of the selected points were reliable homologous points.

When the overlap is higher than 2 images, the multiplicity is ensured.

[2] https://en.wikipedia.org/wiki/Speeded_up_robust_features

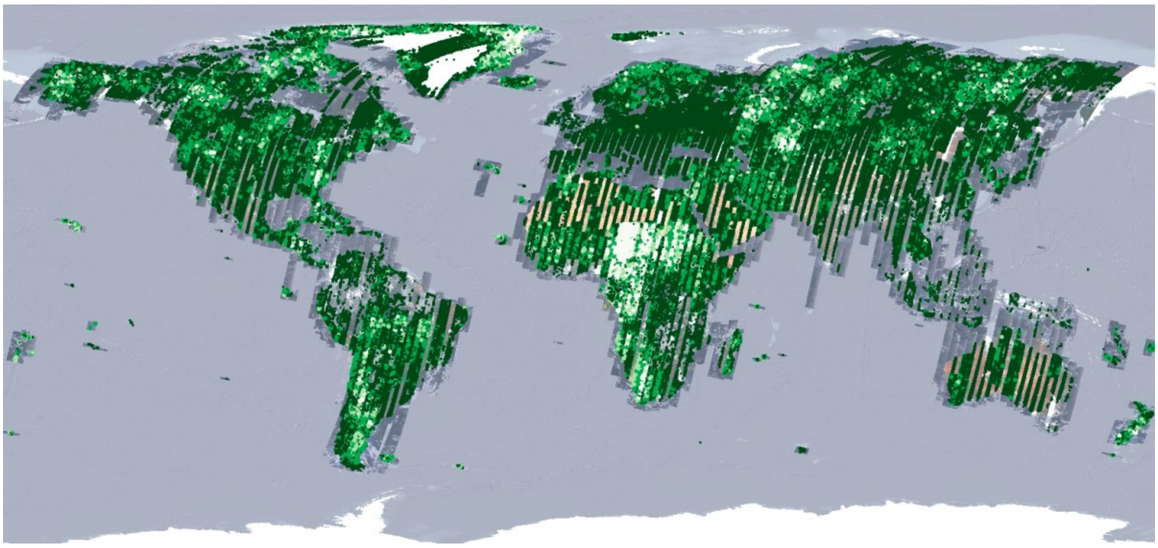

Figure 4: Tie points in the GRI. Dark Green to White: increasing multiplicity

3.2.2.4 Ground Control Points

Using GCPs ensures the absolute geolocation of the images. For the building of the GRI, GCP over the following areas were used:

- ✓ Eurasia & Africa & South America: GCPs mainly coming from the ITRF (International Terrestrial Reference Frame) network [3], or located near airports.
- ✓ Australia: AGRI (Australian Geographic Reference Image) [4] & IGN GCPs
- ✓ USA: GCPs extracted from NAIP (National Agriculture Imagery Program) [5] orthoimagery; GCPs were retrieved from the 300 biggest cities of the USA. The GCPs were selected at road junctions (OpenStreetMap source) so as to obtain image chips with a strong texture.

Over Canada (especially Nunavut and Yukon territories), Greenland and small remote islands, there are most of the time no GCP. Anyway, both good initial geolocation of Sentinel-2 and a proper relative coherence brought by tie points help keeping a correct geolocation.

3.2.2.5 Refining

This step consisted in solving a system using a least square method, where given the observations (tie points and GCPs) the unknowns are the values of the refining. Each unknown and observation data bears a specific weight designed beforehand according to its assumed accuracy.

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[3] https://itrf.ign.fr/en/homepage

[4] https://cmi.ga.gov.au/data-products/dea/116/australian-geographic-reference-image

[5] https://naip-usdaonline.hub.arcgis.com/

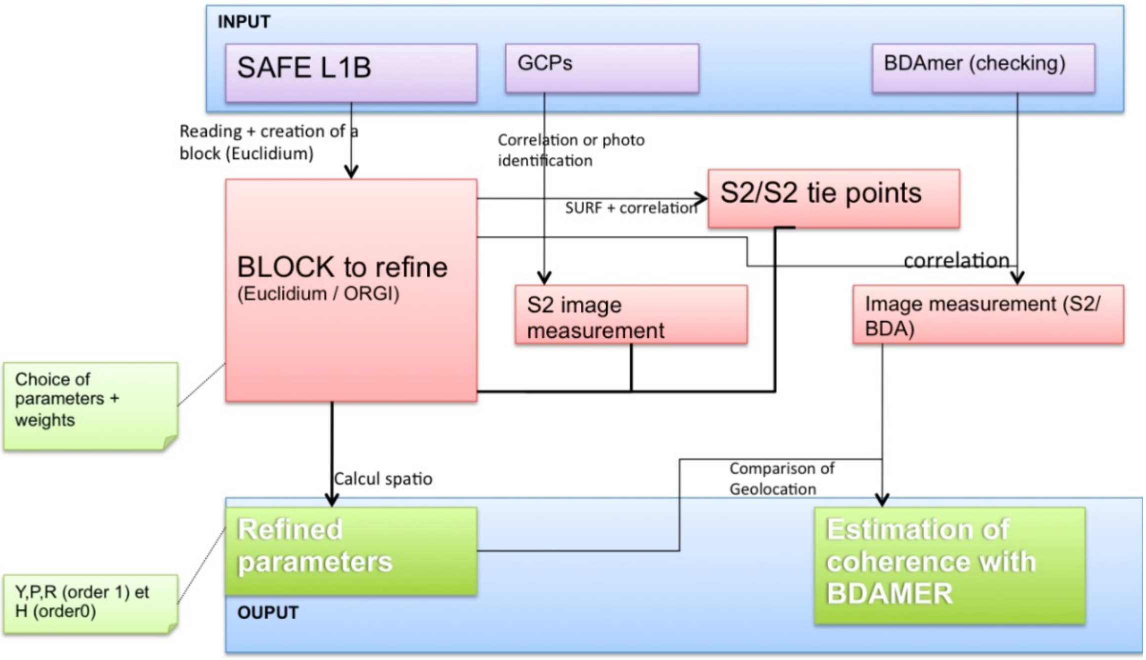

Figure 5: Processing chain of spatiotriangulation

3.2.2.6 Internal validation

Once the block has been refined, the results were carefully analysed. The analysis focused on several points. This analysis was made on the result of the spatiotriangulation (refining values, residual values on the equipment) and using an independent database called *BDAmer* [6]. This database is made of Spot-5 HRS imagery that has been carefully geolocated using GCPs and tie points. IGN retrieved points of interest from this Spot-5 dataset of images and turned them into new GCPs, for further geometric control of other image datasets.

3.2.2.6.1 Analysis of the tie points

A warning was raised on a product when:

- ✓ more than 3% of the tie points are filtered at spatiotriangulation step
- ✓ a product has less than 20 tie points

Then all the warnings were analysed, and a correction was made if necessary.

[6] https://www.isprs-ann-photogramm-remote-sens-spatial-inf-sci.net/V-2-2020/15/2020/isprs-annals-V-2-2020-15-2020.pdf

3.2.2.6.2 Analysis of the relative coherence

The residual values on tie points in the spatiotriangulation provide information about the relative coherence between the products. The analysis consisted in providing statistics on each overlapping area between the images. It helped knowing how dense each image is equipped, and how coherent each pair is.

3.2.2.6.3 Analysis of the absolute coherence

To qualify the absolute geolocation accuracy of the GRI, IGN relies upon the internal *BDAmer* GCP database. IGN retrieved points of interest from this Spot-5 dataset of images and turned them into new GCPs, for further geometric control of other image datasets.

In this case, Sentinel-2 images are correlated with *BDAmer* points of interests, it is a favourable context since both images have common characteristics: same resolution, same spectral band.

The overall accuracy of the *BDAmer* is sufficient to qualify Sentinel-2 GRI.

Consequently, in this context, *BDAmer* can be considered as the reference.

This database is available on most territories, as shown on the map below.

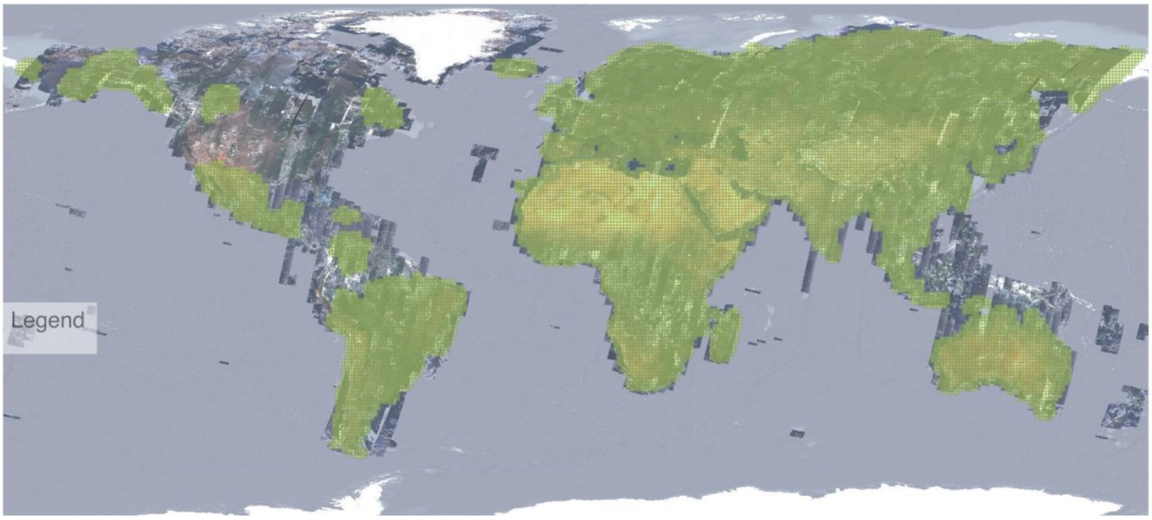

Figure 6: Availability of BDAmer

3.2.2.6.4 Analysis of the geometric performance at global level

For each image both absolute and relative geometric shifts were analysed.

The absolute shift corresponds to the comparison between L1B initial model and L1B refined model geolocations. Under the hypothesis that Sentinel-2 geolocation performance is about 10 m @ 95%, a warning was raised as soon as the observed shift was higher than 10 m.

The relative shift corresponds to the comparison between L1B geolocations after refining in the continental block and after refining in the final global block.

Every warning was analysed manually. The recomputing of the spatiotriangulation step was made if necessary. It was a manual analysis to decide whether or not the recomputing had to be made.

3.2.3 External Validation

Each time a GRI block has been generated and internally validated, an independent validation performed by another team was made.

It consisted in:

- ✓ the correlation of GRI products with GCPs coming from Pleiades 1b imagery (different from the ones used during the refining process),
- ✓ a relative validation between data strips.

The results of this validation are provided in the Multi-Layer L1B Validation Report ([L1B-GRI-VAL]).

4. Product Quality Performance

4.1 Geographic coverage

The GRI worldwide geographic coverage obtained is shown on Figure 7.

It also includes a long list of remote islands. ("remote" means too far from a continent to be linked to it).

Here is the list of remote islands:

> Iceland, New Zealand, Jan Mayen Island, Azores archipelago, Madeira, Canary Islands, Cape Verde, La Réunion, Mauritius, Rodrigues Island, Seychelles, Falkland islands, Galapagos, St Lawrence Island, Hawaï, Kiribati (partial), Caroline Island, Flint Island, French Polynesia (partial), Samoa, Niué, Neaifu, Tonga, Chatham Island, Pitt Island, Fidji islands, Vanuatu Archipelagos, New Caledonia, Solomon (partial), Svalbard (partial), Commander Island, South Kurill Islands, French Marquesas (partial), Kerguelen, Aleutes (partial), St Matthew island, Marianna Island (partial), Clipperton, Pohnpei island, Kosrae Island, Crozet islands, Socorro island, Guam island, Easter Island, Admiralty island, Wrangel island, Christmas island, Saint Helena, Tristan da Cuhna, Inaccessible island, Prince Edward islands, Guadalupe.

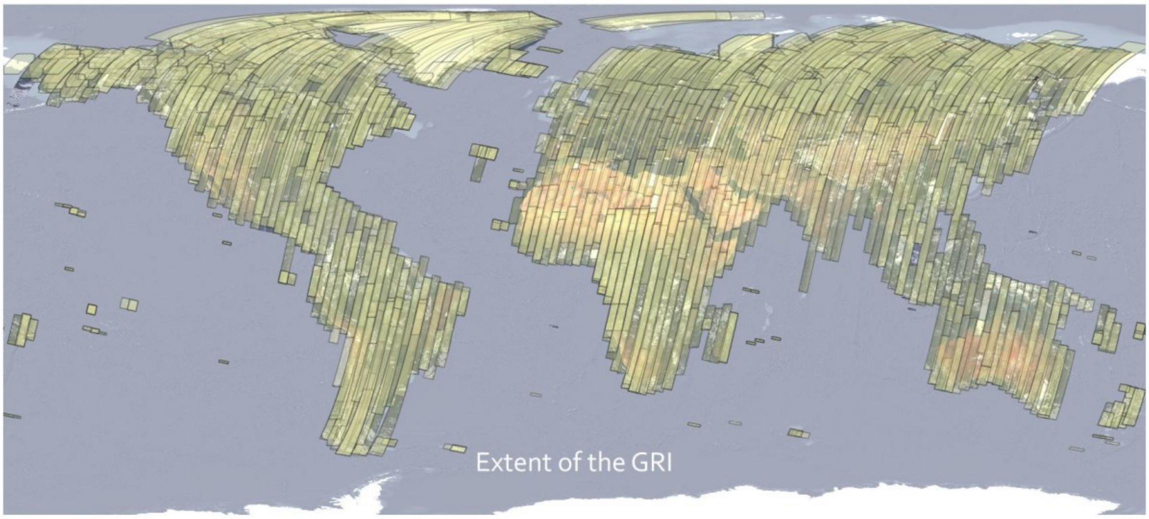

Figure 7: Extent of the GRI

4.2 Coverage by orbit

Except relative orbit 109, all the Sentinel-2 orbits are covered by the GRI.

However, with regards to the numerous constraints (climate, clouds, season, polar night, etc...) and despite a very strong effort, some few areas could not be covered by the GRI. They are described in the following sections.

4.2.1 Orbit R109

Orbit R109 is empty. Indeed, this orbit is completely located over the sea, except a short part passing over Svalbard, where no suitable image was found.

4.2.2 Greenland & Northern Canada

The coverage of Greenland includes numerous orbits with very strong overlap. All the orbits could not be completed but at least the geographic coverage is ensured. A very careful selection work has been achieved in order to get some points on the rocky parts of the shore. Only images acquired in July and August were selected for that purpose. At other seasons, the landscape is completely snowy; therefore, it is not possible to select images suited to the GRI.

Remark: Image radiometry over snowy areas is not suited to a correlation process (e.g. a mask should be applied): searching for homologous points over snow or ice shelf is highly risky due to the fact that the landscape observed is not enough perennial.

There are also known missing parts over Nunavut and Yukon territories (Northern Canada) for the same reasons as over Greenland.

4.3 Overlap

The overlap in the GRI varies according to the areas and depends on the way the GRI was built. Indeed, an important overlap was planned at continental block intersection, and in general, equatorial areas have also an important overlap so as to reduce the final cloud rate.

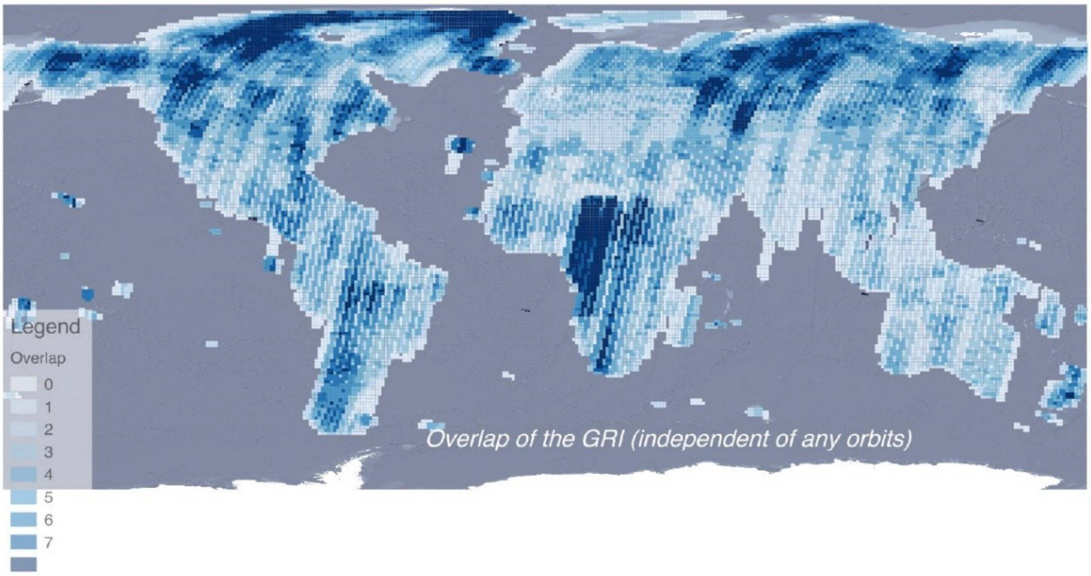

Figure 8: Overlaps in the GRI

4.4 Known issues or supposed weaknesses

4.4.1 Lack of GCPs

As GCPs were not available for the GRI building everywhere in the world so as to equip all images of the GRI, there could be some weaknesses in some parts of the globe.

In particular, Papua New Guinea, Indonesia and Philippines islands can be considered as areas of doubts for several reasons: they are composed of many islands some of them hardly linkable with each other through neighbouring images, due to the lack of overlap between neighbouring orbits at the equator. Moreover, the cloud cover is almost permanent. According to such conditions it is risky to rely on automatically identified tie points.

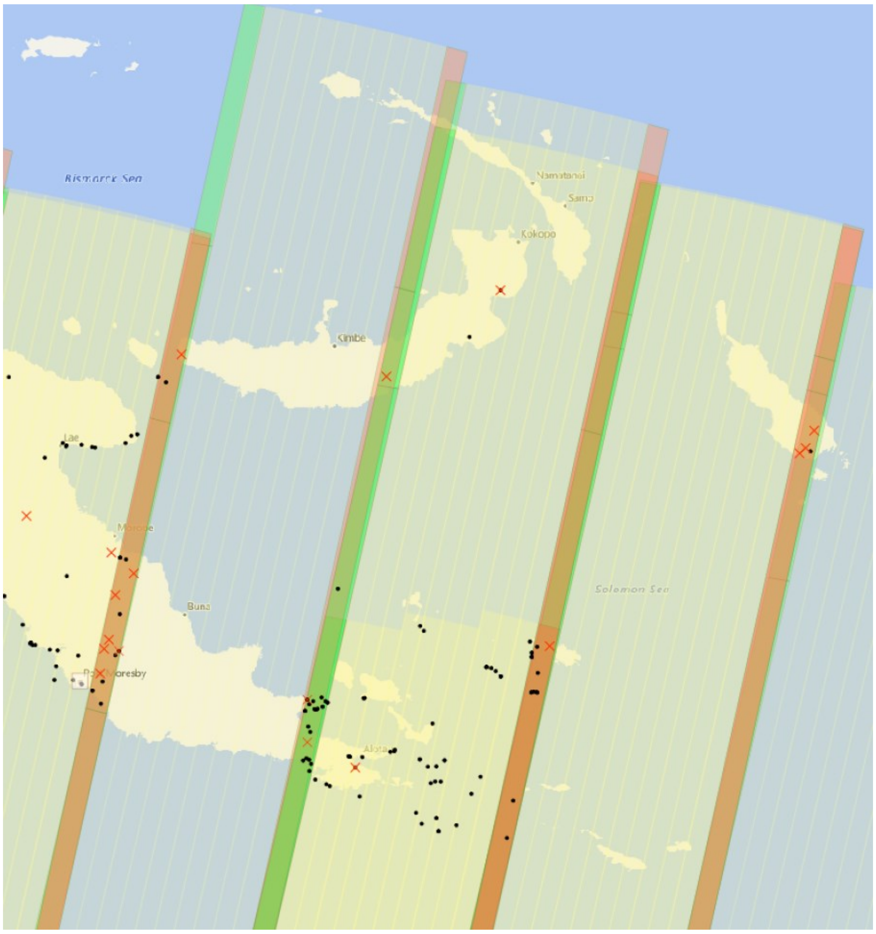

Figure 9: Example of hardly linkable territories over Papua New Guinea. (Red and black points are respectively invalid and valid tie points)

North Canada & Greenland are also geographic areas without GCP. At this latitude (>60°), the overlap between neighbouring orbits is maximum. Consequently, tie points can be found on many images and thus allow ensuring a robust registration between them. In theory we should rely on the good initial geolocation of Sentinel-2. But this geolocation performance depends on the latitude, so that without GCP, we may depend on this error.

The figure hereafter shows this dependency.

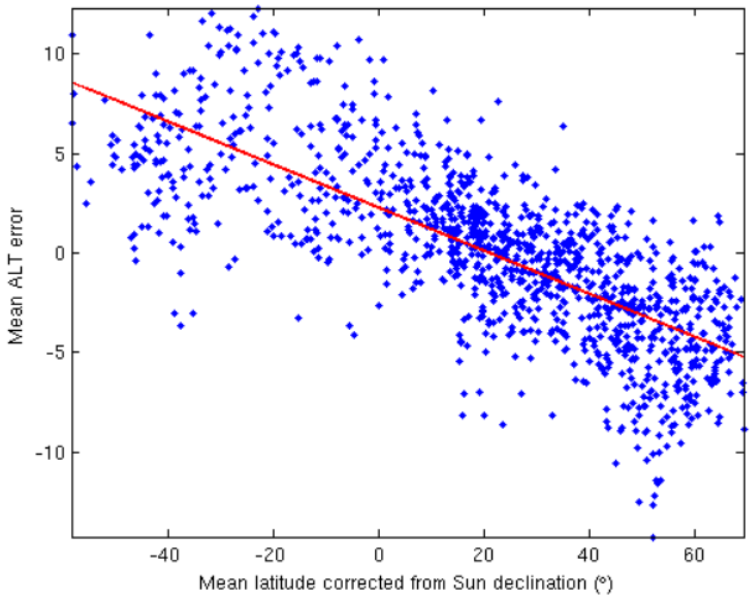

Figure 10: Mean along track error (m) according to the latitude

4.4.2 Missing detectors

Due to an issue with the tool used to retrieve the L1B products for the GRI, some of them are missing some detectors. These products were anyway used as it was not an issue for the purpose for which the GRI was built, i.e. the refining of the S2 products.

4.5 Absolute geolocation performance of the GRI

The geolocation performance is expressed using the formula:

$$\sqrt{BDAmerAccuracy^2 + MeanResidual^2}$$

where *BDAmerAccuracy* is 5m and MeanResidual is the mean residual value of the check points within a square degree.

The statistical results are expressed within tiles of 3 deg^2 x 3 deg^2, so as to keep a sufficient density, in a sliding window of 1 deg.

Initial budgets showed that an accuracy of 9 m on the GRI is needed to reach the 12.5 m CE95 performance on the L1C. Figure 11 shows a global performance of about 7 m. This value is coherent with local CNES validation using Pleiades imagery (see [VAL-ML-L1B-GRI] for details on this validation). When less than 100 points per square degree are provided, the performance is not provided, considering that the value may not be representative.

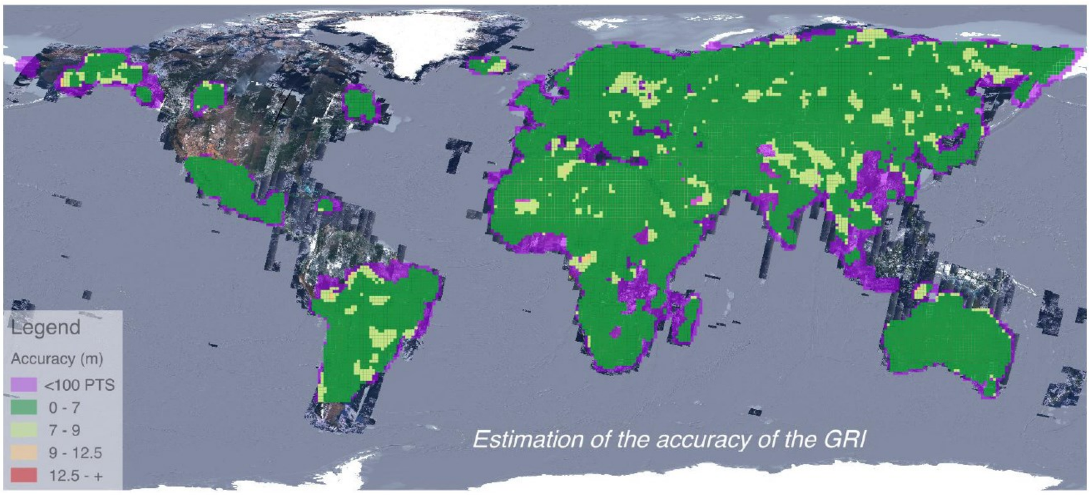

Figure 11: Map of accuracy of the GRI

4.6 Relative coherence

4.6.1 General results

The analysis of the relative coherence (see section 3.2.2.6.2) shows an excellent coherence between the intersecting products.

Bad results are rare, they are usually due to the fact that there are too few tie points within the intersections to compute a significant result (e.g. 3 points).

This analysis also highlights the fact that there may remain tie points to be filtered in these areas. Eventually, the density of the equipment should also be increased locally.

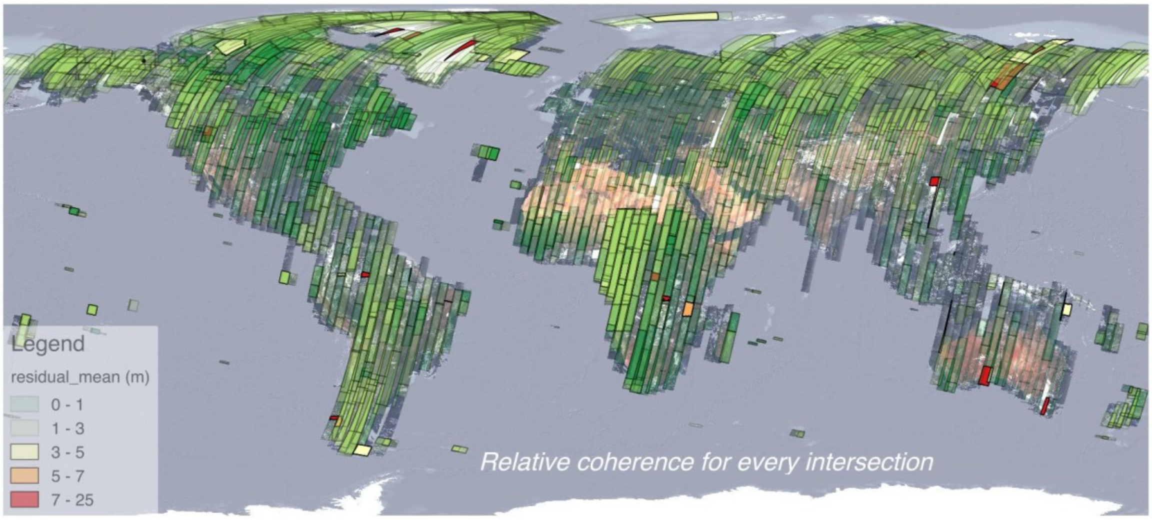

Figure 12: Relative coherence between intersections

4.6.2 Limits of the analysis

- ✓ Only intersecting pairs with at least 1 tie point are presented. If no tie point is found in an intersecting pair, there is no value but there are many chances that the pair is not perfectly coherent (unless a third image is linked to the 2 first ones).
- ✓ The given value is a mean value taking into account the whole intersection. Locally there may be variations (e.g at borders, oscillations etc.). Other criteria such as the distribution of the tie points within the intersection are not considered.
- ✓ Intersections with few tie points are not represented because the value is probably not significant. Unfortunately, they have more chances to be less coherent.
- ✓ Tie points are not the best points for checking, since they are used within the bundle adjustment (spatio-triangulation). Thus, they are not independent.

Finally, the provided value should be interpreted as an indicator of coherence.

4.6.3 More interpretable information

The map in Figure 12 insists on the overall coherence of the GRI, but it does not point out possible issues. Consequently, we show hereafter the most (resp. the less) coherent intersecting pair in a square degree, by plotting the best (resp. the worst) indicator of every intersecting pair present in a square degree.

The interpretation is that if the most coherent pair has a bad indicator, the GRI is not coherent in this area. If the less coherent pair has a good indicator, the GRI can be considered as coherent in this area.

In the figures below, the analysis is limited to homologous points between pairs from the same relative orbit.

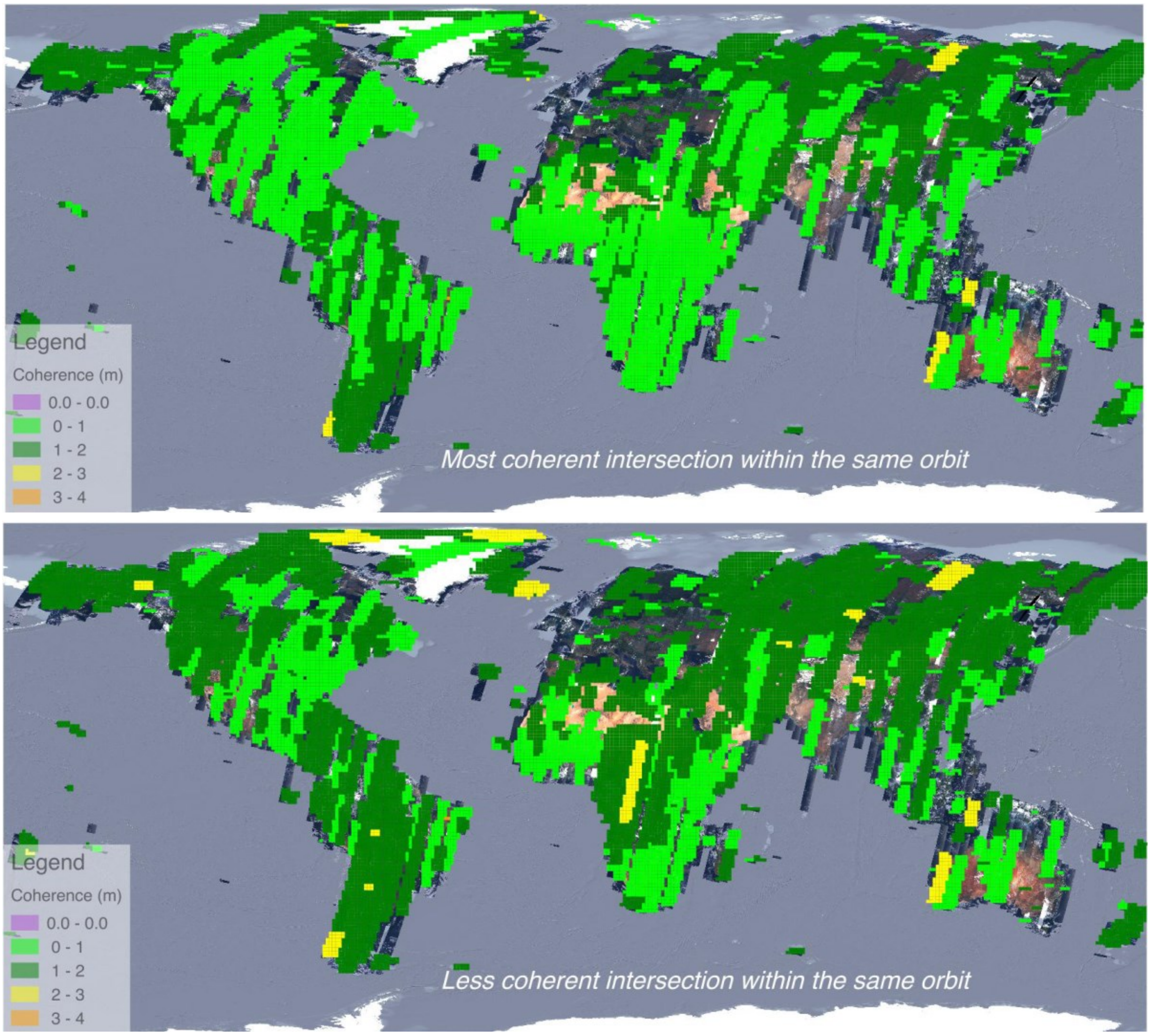

Figure 13: Indicators of relative coherence within the same relative orbit

5. Product Format

The Multi-layer L1B GRI is organized in a set of directories each one corresponding to one relative orbit number (from 1 to 143, except 109). The highest-level directory, or main folder, is named "GRI''. Within each orbit folder, the Level-1B products are provided as sub-folders. Inside each orbit folder there will be a set of unitary Level-1B User Product (with a single band) as specified in [PSD].

5.1 High-Level Structure

Figure 14 provides a high-level view of the GRI structure.

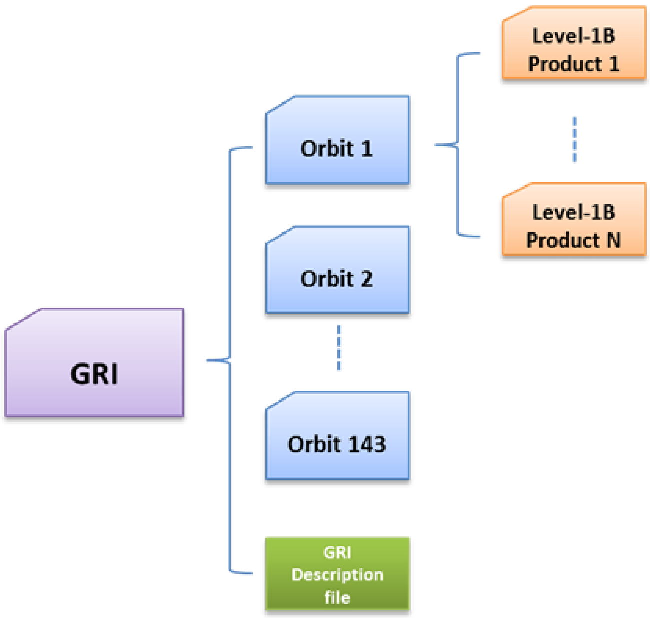

Figure 14. GRI high-level physical structure

The format of the GRI is the following: L1B products are in SAFE format, ordered by relative orbits, and compressed in a tgz folder.
The GRI products naming doesn't follow the Compact Naming convention described in the Sentinel-2 PSD, as this convention didn't exist yet when the generation of the GRI started.
The Multi-Layer L1B GRI contains about 900 L1B products, weighs ~2.8 TB, and the tgz folders contains about 56 million files.

It is also important to notice that as the GRI has been built using products from different periods, the format of the products may slightly differ, according to the PSD version applying to the acquisition period of the used product.

Consequently, it is not easy to handle the image data in this format.

5.2 Product Structure / Naming Convention

All the products composing the GRI are listed in a "GRI Description File".
The GRI per orbit directory format is described in Section 5.2.1.
The GRI Description File format is described in Section 5.2.2.
The unitary Level-1B user products format is described in Section 5.2.3.

5.2.1 GRI Orbit Directory Format

The naming convention of the GRI orbit directory follows the naming convention defined hereafter:

MMM_CCCC_TTTTTTTTTT_<Instance_ID>

where:

- MMM = Mission ID = S2_
- CCCC = File Class = OPER
- TTTTTTTTTT = File Type (Category + Semantic) = AUX_GRIXXX
- where:
  - XXX = Relative Orbit (001-143)
- <Instance ID> = <Site Centre>_<Creation Date>_<Validity_Time_Period>ssss_yyyymmddThhmmss_VyyyymmddThhmmss_YYYYMMTDDHHMMSS

  where:
  - ssss_yyyymmddThhmmss is the <Instance ID> mandatory prefix for Site Centre (equal to 'MPC_') of the file originator and Creation Date.
  - _VyyyymmddThhmmss_YYYYMMDDTHHMMSS = Validity Time Period

An example of S2 GRI per orbit directory name is:

S2__OPER_AUX_GRI123_MPC__yyyymmddThhmmss_VyyyymmddThhmmss_YYYYMMDDTHHMMSS

5.2.2 GRI Description File Format

The GRI Description File main scope is to maintain the GRI under configuration control supporting and describing each new delivery of the entire or of part of the GRI. The GRI Description File includes a complete reference to the complete GRI dataset. The format and content of GRI Description File is specified in a .xsd (gs2_gri_description_file.xsd) schema.

The naming convention of this XML file follows the naming convention defined hereafter:

MMM_CCCC_TTTTTTTTTT_<Instance_ID>.<FORMAT>

where:

- MMM = Mission ID = S2_
- CCCC = File Class = OPER
- TTTTTTTTTT = File Type (Category + Semantic) = GRI_DESCRI
- < instance ID> = ssss_yyyymmddThhmmss_VyyyymmddThhmmss_YYYYMMTDDHHMMSS_vvvv
  where:
  - ssss_yyyymmddThhmmss is the <Instance ID> mandatory prefix for Site Centre (equal to 'MPC_') of the file originator and Creation Date.
  - VyyyymmddThhmmss_YYYYMMDDTHHMMSS = Validity Time Period
  - vvvv is the version number which follows the same versioning of the GIPPs. Chronological number increments automatically for each new version of the parameters file (regardless of the validity dates). It is a responsibility of the GRI provider to take care of the versioning of the supplied files.
- <FORMAT>= XML

An example of S2 GRI Description file name is:

S2__OPER_GRI_DESCRI_MPC__20150424T120700_V20090101T000000_20181231T235959_0001.xml

5.2.3 Unitary Level-1B User Product Format

The physical format of each unitary Level-1B User Product is defined in the [PSD].
Each unitary Level-1B User Product is in Sentinel SAFE format and it is composed by a set of granules and datastrip PDIs (Product Data Items).

The naming of the unitary Level-1B user product directory is in line with Level-1B user products naming convention:

MMM_CCCC_TTTTTTTTTT_<Instance_ID>.<FORMAT>

where:

- MMM = Mission ID = S2X
- CCCC = File Class = OPER
- TTTTTTTTTT = File Type (Category + Semantic) = GRI_MSIL1B
- < instance ID> = ssss_yyyymmddThhmmss_ROOO_VyyyymmddThhmmss_YYYYMMTDDHHMMSS
  where:
  - ssss_yyyymmddThhmmss is the <Instance ID> mandatory prefix for Site Centre (equal to 'MPC_') of the file originator and Creation Date.
  - OOO = Orbit Number
  - yyyymmddThhmmss = Start Time

- YYYYMMDDHHMMSS = Stop Time
- <FORMAT>= SAFE

An example of S2 GRI product main directory is:

S2A_OPER_GRI_MSIL1B_MPC__20150424T120700_R054_V20090101T000000_20181231T235959.SAFE

6. User Guide

6.1 Use of the GRI by the Sentinel-2 Level-1 processor

Most information and figures of the paragraph are extracted from [S2-L1-ATBD].

6.1.1 Viewing model refining principle

The viewing model consists in:
- ✓ A dating model, allowing to know precisely the dating of the beginning of each line.
- ✓ Tabulated orbital data, allowing to know the position of the spacecraft at the time of the line acquisition.
- ✓ Tabulated attitude data, allowing to know the orientation of the spacecraft at the time of the line acquisition.
- ✓ Viewing directions in the spacecraft piloting frame.

The viewing model allows to compute the viewing vector (line of sight) at the time of the pixel acquisition.

By intersecting this viewing vector with an Earth model, it is possible to compute the geolocation (or direct location) of the pixel, and inversely, to compute the position in the image of a point located on ground (Image location or inverse location).

However, the attitude and orbital data are known with a given precision, due to the sensor's inaccuracy: GPS, attitude sensors. There may be also thermo-elastic effects at the scale of the orbit, which affect the geolocation performances. Geometric refining consists in adding polynomial corrections to the viewing model, so as to improve the geolocation performances.

To correct the position data, a polynomial function of time is estimated. The polynomial coefficients are estimated by a mean square regression called the spatio-triangulation. The polynomial functions coefficients, correcting the attitude and orbital information used by the location functions (geolocation function and inverse location function), are computed so as to minimise the average residual values (cf. Figure 15) of a large number of Ground Control Points (GCP). To sum up, the refining outputs are the polynomial functions correcting attitude and orbital data.

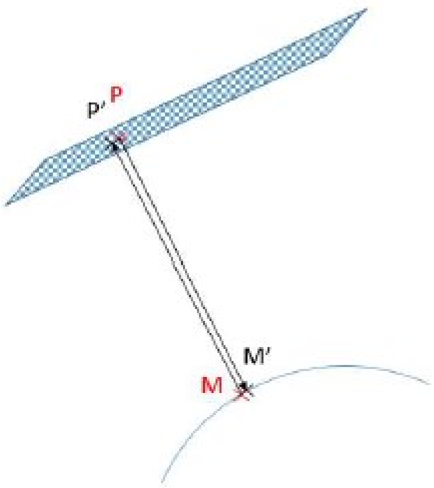

Figure 15. Illustration of residuals distance values (P-P') and (M-M')

For finding GCP necessary to the refining, a correlation is performed between the reference segment (Product of the Multi-Layer L1B GRI) and the segment to refine.

The operational S2 refining process is split in 4 steps:

- ✓ Selection of the L1B GRI product
- ✓ Resampling in a common geometry
- ✓ Correlation and GCP selection
- ✓ Spatial triangulation

6.1.2 Ground Control Points Selection in Sentinel-2 Level 1 processor

6.1.2.1 GRI Products Selection

The first step is to select all products of the Multi-Layer L1B GRI that intersect the Product to refine. To limit processing time, in Sentinel-2 Level 1 processing chain, only products of the same relative orbit are tested by intersection of Datastrips footprints. Then granules of each intersecting Datastrips of the GRI are also selected.

6.1.2.2 Common geometry resampling

It is then necessary to resample the two or more (overlap of Multi-Layer L1B GRI Products) segments to compare in a common virtual geometry, because of Sentinel-2 specificities: the images are split in 12 detectors and the pointing precision is at worst 2 kms. This viewing model of the common virtual geometry is computed:

- ✓ By constructing an average regular dating model over the segment to refine footprint
- ✓ By picking the attitude and orbital data of the segment to refine and by computing regular viewing directions, as if it were a push broom sensor, composed of one single detector, covering the whole Sentinel-2 swath.

The two images are then resampled (only B04 as only B04 is available in the Multi-Layer L1B GRI), using the resampling grids, an interpolation filter and the definition of interest area for each detector, as illustrated in Figure 16. Then the correlation is performed between two monolithic images composed of one single detector. This guarantees that the processing is homogeneous for all the detectors and allows detection of yaw angle. It has to be noticed that this common geometry is only used for the correlation process for finding GCP and is then discarded.

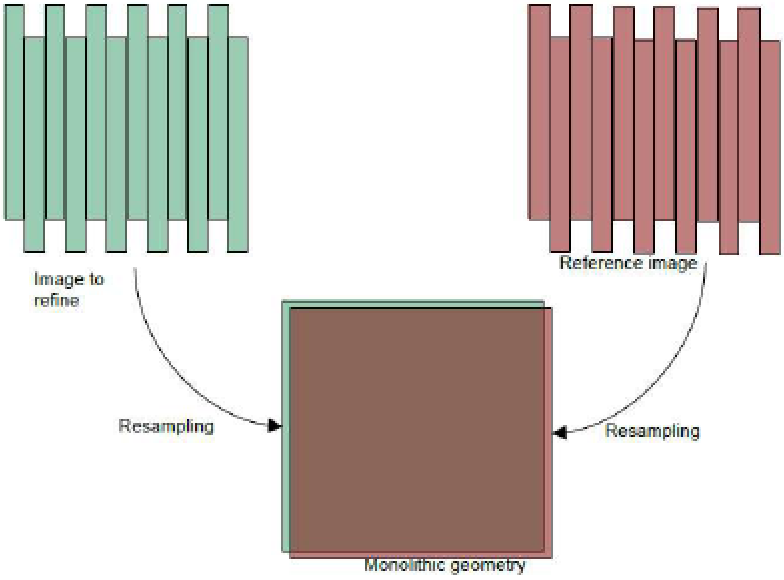

Figure 16. Resampling in monolithic geometry.

6.1.2.3 GCP Collection

In the common geometry, correlation can then be computed. As the refining required an homogenous spreading of the points collected, the Datastrip is cut in several Virtual parts (VATF). Each zone will have a density min and max of points to collect. The principle of the Sentinel-2 operational processing is:

- ✓ To define a regular grid of points on each zone,
- ✓ Filter out each point in the masked area,
- ✓ Correlate (with a quadratic fit) small chips around each remaining point with little larger GRI chips. If the correlation results are high enough, then the point is kept as considered as a GCP and coordinates are kept. If several GRI product areas are available, the coordinates kept are the mean of the coordinates of all GRI for this point,
- ✓ Filter out outsider points with a polynomial filter for each zone,
- ✓ Check the density of the point collected on each zone (points of all iterations). If a zone does not have the required density, the grid is densificated and the process start back from step 1. If a zone has too many points collected, best points in term of curvature are kept.

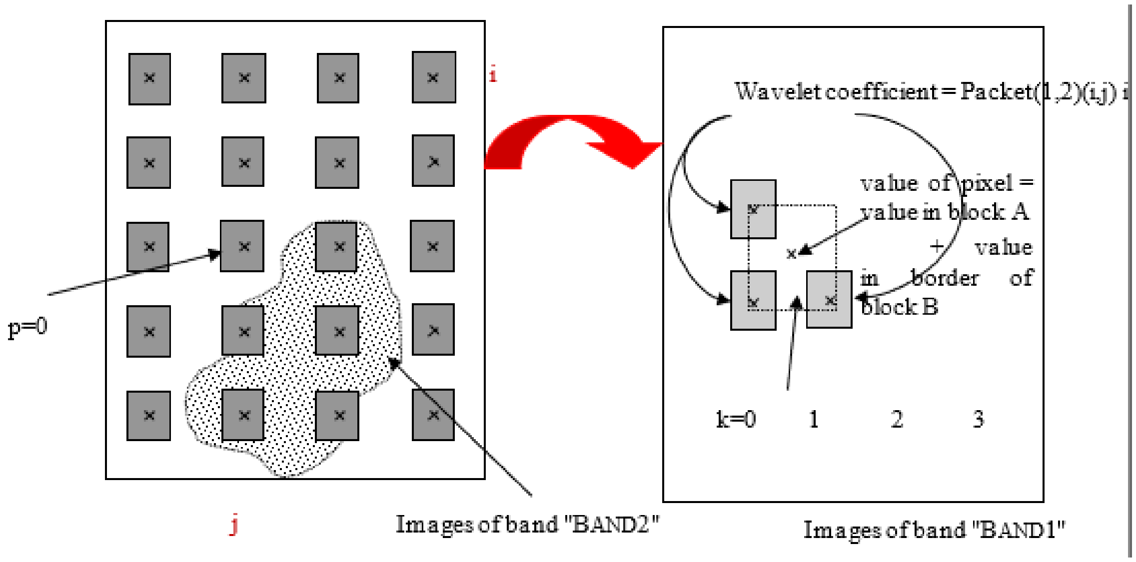

Figure 17. Example of a grid with chips.

On the right the search window of the Chip of the product (left) that is larger than the product. The chip of the product is compared with several chips of the GRI around the same point.

6.1.2.4 Spatio-triangulation

The geometric refining of the viewing model is done by spatio-triangulation using GCPs extracted at the previous step, with the parameters to refine and for each, the degree of the modelling polynomial function, chosen among:

- ✓ Spacecraft gravity centre position: X, Y, Z in WGS and type of correction: constant or polynomial function of time.
- ✓ Attitudes: roll, pitch and yaw, type of correction: constant or polynomial function of time.
- ✓ Spacecraft to focal plane transformation: rotation (3 angles), translation, homothetic transformation, type of correction: constant or polynomial function.

The default setting is given below and illustrated in Figure 18:

- ✓ Attitudes:
  - roll, pitch, yaw in spacecraft frame
  - correction modelled by a bias and a drift
- ✓ Spacecraft gravity centre position:
  - X, Y, Z in WGS84
  - correction modelled by a second-degree polynomial function

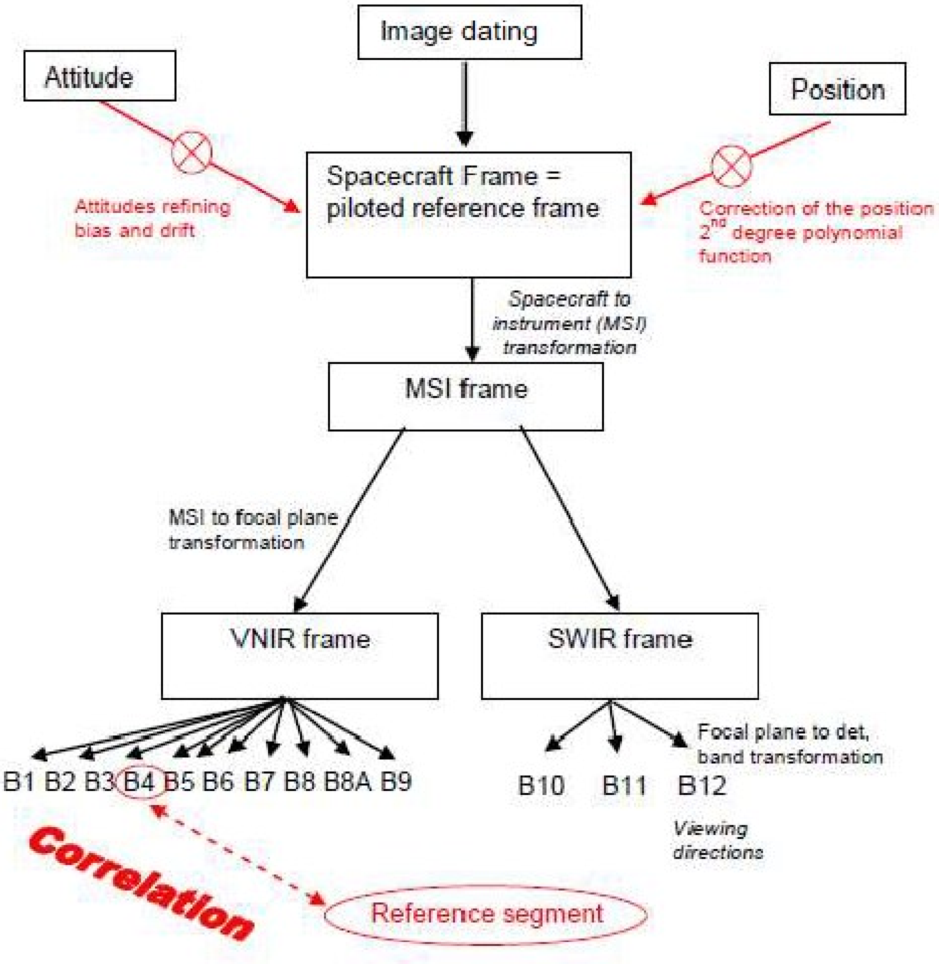

Figure 18. Viewing model and parameters to refine.

6.2 Use of the Multi-Layer GRI for other missions

The Multi-Layer L1B GRI is currently used by the Sentinel-2 operational chain to mainly improve the global multi-temporal consistency and in addition the absolute geolocation accuracy. The idea is to refine products by fitting them to the GRI (see section 6.1).

Using the same principle, one might use the Multi-Layer L1B GRI **to refine the absolute geolocation of its satellite data** and therefore enhance the multi-temporal consistency, knowing that the Multi-Layer L1B GRI has a single spectral band with single resolution: the resolution of the GRI is 10 m with a central wavelength around 665 nm. It is then recommended to use spectral length close to it.

Regarding the resolution, the recommendation is to resampled images if needed, up to 50 m. Resolution outside of this range would not really benefit from the quality of the GRI.

However, the Multi-Layer L1B GRI requires some Sentinel-2 good knowledge to be used, anyway it is for instance possible to use it to:

- ✓ **redefine new GCP** at lower resolution (> 50 m for example),

- ✓ have more points in specific area than the ones available in the L1C GCP GRI, with a reminder that this GRI shall be used in a statistic way and not layer by layer of tiles.

The Multi-Layer L1B GRI, with its accurate geometric performances, may also be used to **estimate the accuracy of Satellite Data**. As it will require some specific knowledge of Sentinel-2 sensor, it is recommended to then use the Multi-Layer L1C GRI (see [PHB-L1B-L1C-GCP-GRI]). However, the Multi-Layer L1B GRI can still be used, to compute tie points by changing the geometry of the GRI or the Product, and then estimate a geometrical accuracy regarding the GRI.

7. Distribution, License, and Copyright

7.1 Distribution

7.1.1 Distribution website

The Multi-Layer L1B GRI can be found on Sentinel Online Website. The Multi-Layer L1B GRI can be downloaded and publicly distributed to the international user community.

The Product Handbook and the Validation Report are also made available to the public on the dedicated website.

7.1.2 Distribution format

The Multi-Layer L1B GRI can be downloaded per orbit.

Each downloadable item consists in a .TGZ file containing an orbit directory (as defined in section 5.2.1).

7.2 License and copyright

The Multi-Layer L1B GRI is distributed under Creative Commons Zero (CC0) license.

Under this license, users can copy, modify, distribute, and work with the Multi-Layer L1B GRI, even for commercial purposes, all without asking permission.

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