S2 MPC

Multi-Layer Copernicus Sentinel-2 GRI in Level-1C - Validation Report

Ref. S2-MPC_VAL_MultiLayer_L1C_GRI

The power of innovation

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V1	2023-05-31	Creation	
V2	2023-06-26	Update crossvalidation with corrected tools taking into account that several datastrips are duplicated	§4: Validation Results
V3	2023-07-07	Update of the document title	

Table of contents

1. Introduction

1.1 Purpose of the document

This document aims at providing the results of the validation of the Multi-Layer L1C GRI.

This document:

- ✓ Provides a reminder of the Multi-Layer L1C GRI specifications in section 2,
- ✓ Describes the data and methodology used for the validation in section 3,
- ✓ Provides the validation results in section 4.

1.2 References

Id	Title	Reference
[PHB-ML-L1C-GRI]	Multi-Layer L1C GRI Product Handbook	S2-MPC_PHB_MultiLayer_L1C_GRI_V1
[PHB-ML-L1B-GRI]	Multi-Layer L1B GRI Product Handbook	S2-MPC_PHB_MultiLayer_L1B_GRI_V1
[S2 PSD]	Sentinel-2 Products Specification Document	S2-PDGS-TAS-DI-PSD, Issue 14.9, 30/09/2021

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.

1.3 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-1C, a granule is a tile (see definition hereafter)

MGRS	Military Grid Reference System [1]: Tiling system on which the Sentinel-2 tiling system is aligned with.
SAFE	Standard Archive Format for Europe [2]
Tile	110 km2 ortho-images in UTM/WGS84 projection. Earth is subdivided on a predefined set of tiles, defined in UTM/WGS84 projection and using a 100 km step. However, each tile has a surface of 110x110km² in order to provide large overlap with the neighbouring (for more details see [S2-PSD])

[1] https://en.wikipedia.org/wiki/Military_Grid_Reference_System

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

2. Product Specifications

The Multi-layer L1C GRI has been derived from the Multi-Layer L1B GRI, which was built to be used by the Sentinel-2 operational processor to improve the geometric performance of Sentinel-2 products.

It shall thus have the same global coverage and geolocation performances as the Multi-Layer L1B GRI.
Please refer to [PHP-ML-L1B-GRI] for more information on Multi-Layer L1B GRI.

In addition, the Multi-Layer L1C GRI shall:

- ✓ be compliant to the Complete Single Tile format, as described in [S2 PSD],
- ✓ include a quality layer (per tile or datastrip),
- ✓ be generated with the Copernicus DEM at 30m horizontal resolution,
- ✓ be generated with the same processor as the one used for Sentinel-2 Collection-1.

Please refer to the Multi-Layer L1C GRI Product Handbook ([PHB-ML-L1C-GRI]) for more information.

3. Data and Validation Methodology

3.1 Data

3.1.1 Multi-Layer L1C GRI

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

- ✓ 12.50 m CE95,
- ✓ multi temporal registration of 0.5 p @ 95%.

It is a set of L1C orthorectified tiles derived from the Multi-Layer L1B GRI (see [PHB-ML-L1B-GRI] for details regarding the Multi-Layer L1B GRI).

The Multi-Layer L1C GRI structure is as follows:

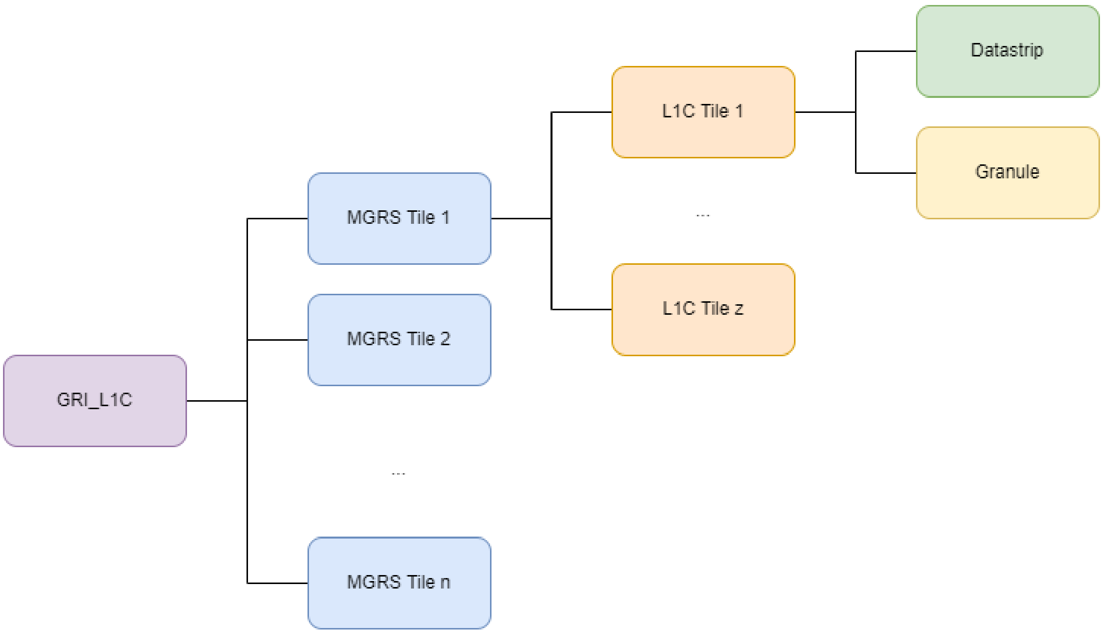


Figure 1. Multi-Layer L1C GRI high-level physical structure

It is organised per UTM tiles (MGRS), and then inside each UTM tile folders, several tile products can be found corresponding to all the overlapped tiles. More information is available in [PHB-ML-L1C-GRI].

They are the data to be validated using additional data presented in following sections.

3.1.2 Subset of previously generated Multi-Layer L1C Tiles

In 2018/2019, a first set of a thousand L1C tiles was already converted from the Multi-Layer L1B GRI. These tiles were generated with a previous version of the Converter, still based on the S2 L1 processor but a former version with a different format and based on 90 m Copernicus DEM.

Those tiles were validated, and it was shown that they had the same geolocation performance as the Multi-Layer L1B GRI. Moreover, their absolute geolocation was also assessed as identical to the Multi-Layer L1B GRI.

Thus, these L1C tiles are good candidates to confirm the right conversion of the new generated L1C Tiles.

3.1.3 L1C GCP GRI

The L1C GCP GRI is a database of points which were extracted from the Multi-Layer L1B GRI.

The extraction consisted in selecting textured features of the landscape within the L1B GRI images. The points are extracted in L1B sensor geometry using the Hessian criteria within the images. A special care was given to the distribution of the points within the image, to ensure that they are evenly spread throughout the L1B datastrip. This method provides textured points but does not ensure the relevancy of the detail: unfortunately, the GRI includes many clouds which are textured too. Therefore, a filtering effort has been made onto these numerous candidates to become valid points.

It is thus important to understand that the L1C GCP GRI, is improperly called base of GCPs, as it is not really composed of Ground Control Points as traditionally used in photogrammetry. The points collected here do not come from ground measurement campaigns (such as GPS), where each point can be used alone since its validity is quite sure.

Hence, it is recommended to work with a consequent set of points, taking advantage of the statistical effect, rather than considering the points independently.

The L1C GCP GRI data are delivered by tiles of 1° x 1°. Each square degree folder contains a JSON file describing the data and containing the list of GCPs for this square degree. A folder contains the L1C images (chips) corresponding to each GCP of the square degree.

This L1C GCP GRI has the same origin (Multi-Layer L1B GRI) and thus has the same extend as the Multi-Layer L1C GRI. Furthermore, both GRI have been generated by two independent methods. Thus, they can be cross-validated.

3.2 Method

The validation of the L1C GRI was done in two steps:

- ✓ Validation of the format of the GRI: 3.2.1,
- ✓ Cross-validation with all L1C GCP of the L1C GCP Database: 3.2.2.

3.2.1 Integrity validation

One requirement is to be compliant to the Complete Single Tile format, as described in the most recent Processing Baseline and PSD 14.9. Hence the format chosen described in section 3.1.1. has to be respected for every generated tile. The integrity validation is hence composed of two parts:

- ✓ Completeness verification: all expected tiles are generated.
- ✓ Format verification: all tiles have the right format and are complete.

The first point was done by checking the list of the several layers of the L1C GRI generated versus an expected list computed by intersection of the L1B GRI footprints versus the GIP_TILPAR (configuration file describing all the Sentinel-2 L1C tiles). The second point was done by checking the tree structure of the GRI generated (check that all the expected files are available with the right naming and that no unexpected files is present in the tree).

3.2.2 Cross-validation with all L1C GCP GRI

Although both the L1C GCP and the L1C tiles were derived from the same L1B GRI Database, they were generated using two different software. They are thus expected to both have the same quality as the Multi-Layer L1B GRI and to be consistent between them. The principle of the cross-validation between the Multi-Layer L1C GRI and L1C GCP GRI is described in hereafter in Figure 2.

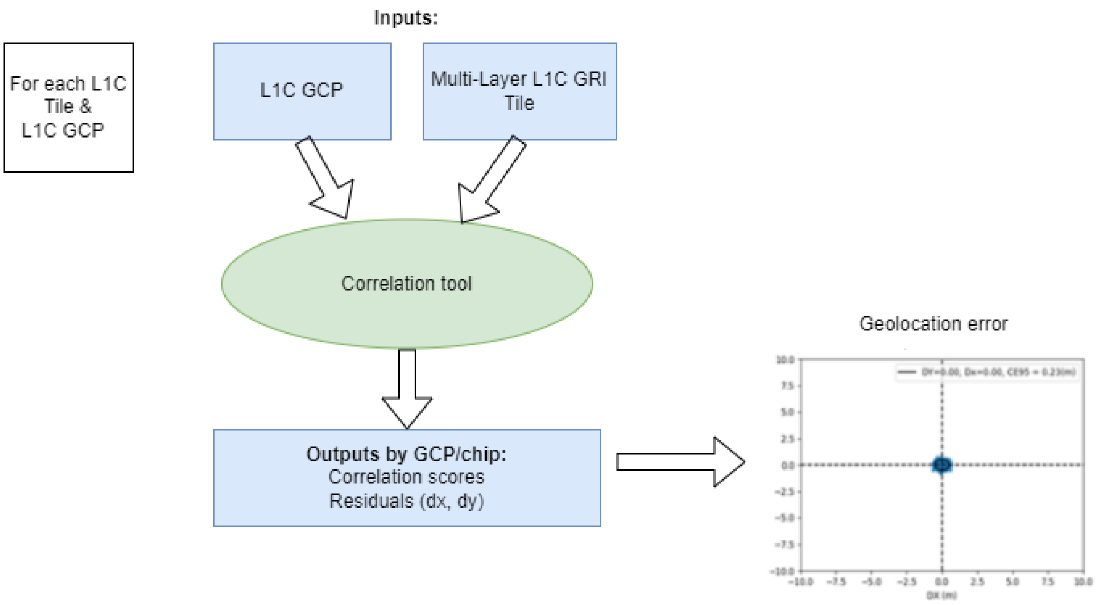


Figure 2. Multi-Layer L1C GRI and L1C GCP GRI cross validation principle

Where correlation tool (shift estimator) can be detailed by:

- ✓ Correlation coefficients are computed for each integer shift of the reference chip towards the chip extracted from the product (shifts in X,Y in the research window size). This is generating the correlation map at pixel step. Then a bicubic interpolation is perform on correlation map around the maximum of correlation in the map at pixel step. From this bicubic interpolation, the subpixel shift is computed, corresponding to the maximum of correlation coefficient.

- ✓ Other parameters related to curvature (curvature and anisotropy) are retrieved by quadratic fit centred on the maximum of correlation coefficient previously defined by bicubic interpolation.

The principle of the process can be summarized in computing a mean shift (by Image of Tile regarding all GCP over it but keeping the CE95 to filter possible correlation issue) for all L1C Tile of the L1C GRI Database based on the correlation tool's results over all GCP. To compute the mean shift by tile, for each chip of each GCP, a correlation with the shift estimator presented above was used. Points that do not correlate or have a correlation under 0.7 or a curvature (absolute value) under 0.05 were discarded. These thresholds have been chosen because they are the ones used in the operational Sentinel-2 processing chain for the refining.

The cross-validation was done in 2 ways, both assessing different aspects of the quality of the L1C GRIs (both Multi-Layer L1C and GCP L1C):

- ✓ The mean over each L1C tile image is computed on only chips that were generated using the same L1B datastrip than the one use to produce the L1C tile
- ✓ The mean over each L1C tile image is computed on all OTHER chips that were generated using other L1B datastrips that cover the L1C Tile (datastrips can come from the same Relative orbit or different ones).

("L1C tile image" is here one image of a MGRS Tile. No to be mistaken with MGRS Tiles that can contain several L1C tile images coming from different datastrip of the Multi-Layer L1B GRI, see 3.1.1)

Scatter plots and statistics on distances of each L1C tile image versus the L1C GCP is then done for the world and by continents.

4. Validation Results

This document will focus on both cross-validation as other results of the first two steps provided coherent results that do not apport any useful information regarding the quality of the Multi-layer L1C GRI. To see the description of checks performed, please refer to section 3.2.

4.1 Cross validation with corresponding Datastrip

This section presents the results of the comparison of L1C images from the Multi-layer L1C GRI versus the L1C GCP chips coming from the same L1B datastrip. This will allow assessing that both GRI are consistent and as they were generated by two different entities with two different software, it can reinforce the confidence in the generation of both GRI and their geolocation.

The following scatter plots presents the result of the comparison for the world:

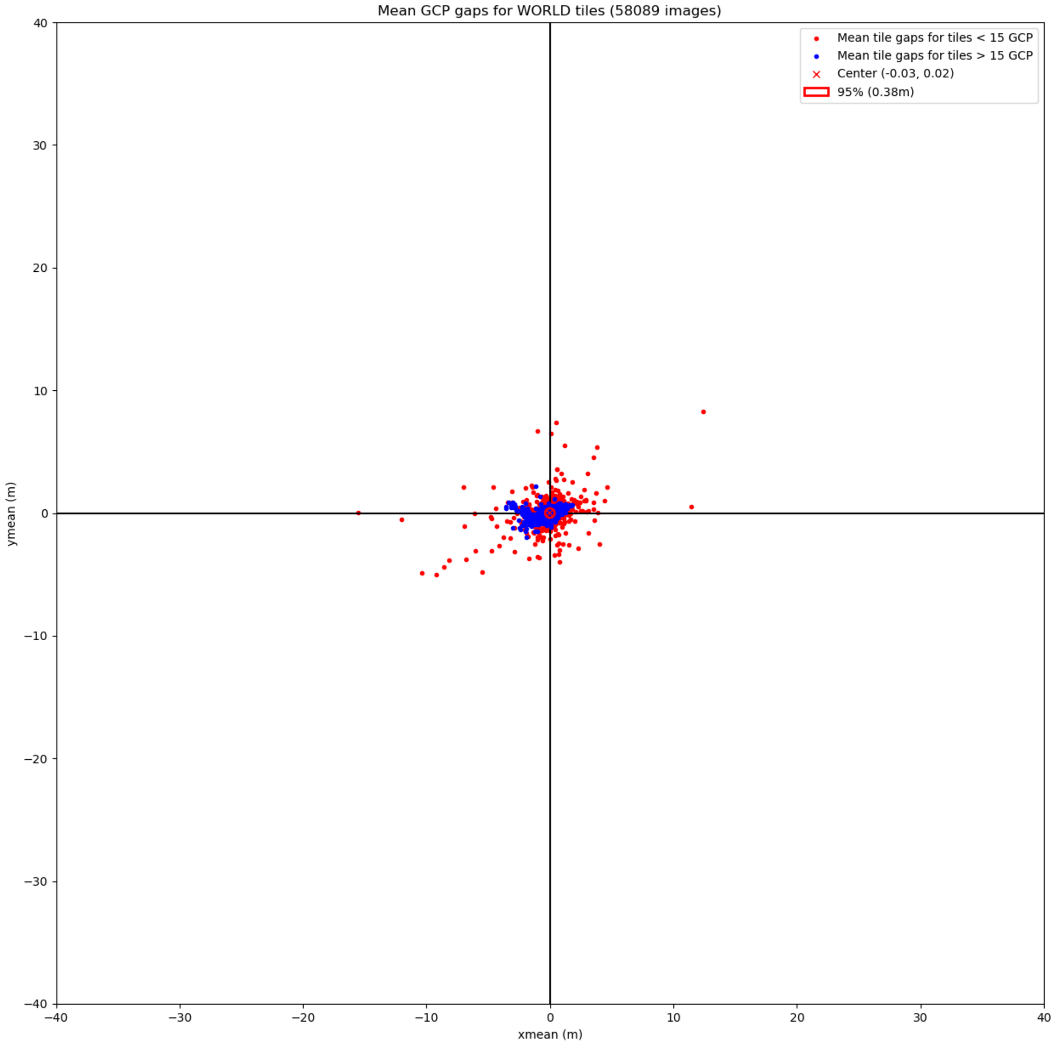
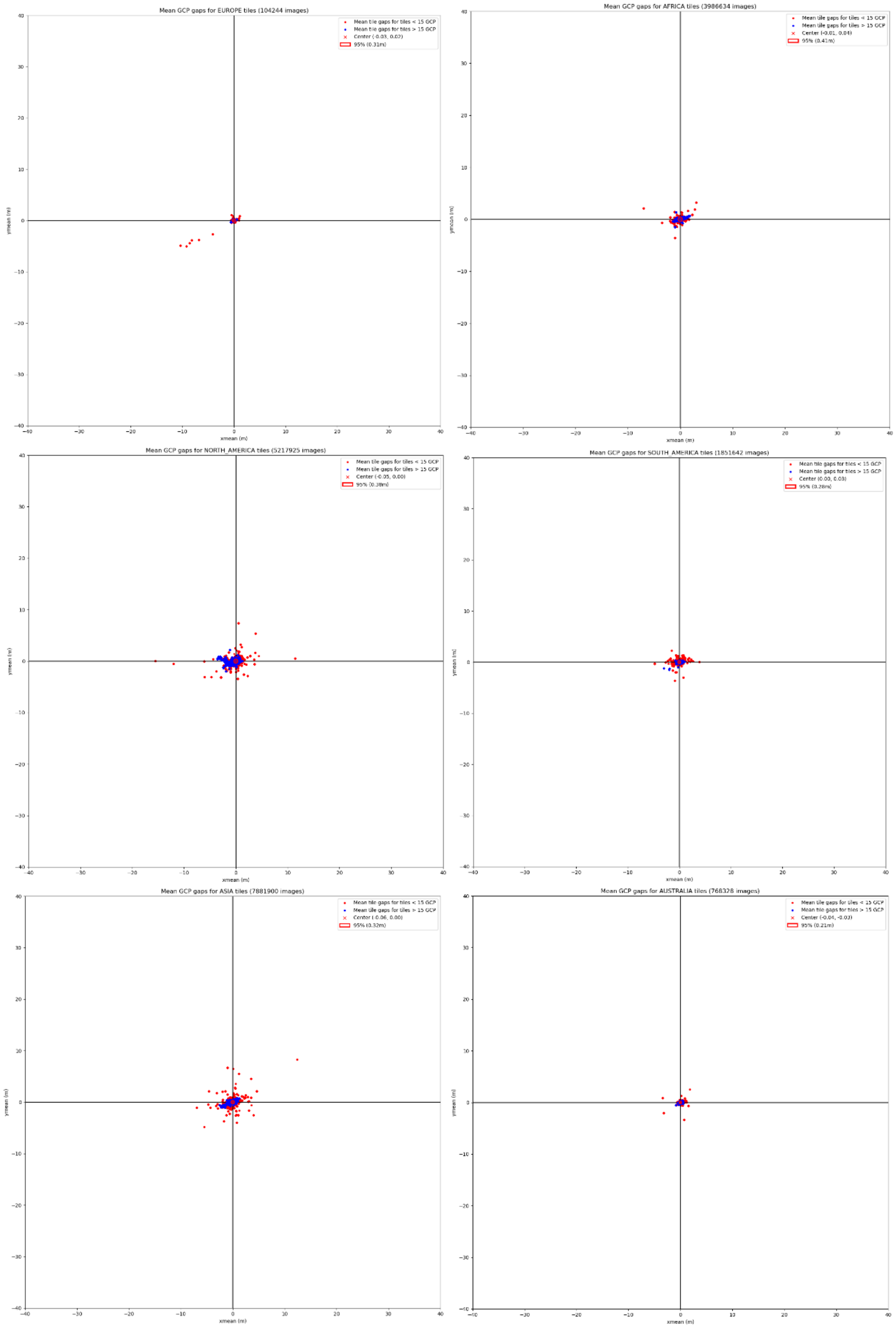


Figure 3. Scatter Plot of shifts over the WORLD between L1C Tile and L1C GCP coming from the same L1B datastrip

Red dots represent L1C tiles for which less than 15 GCP have been found. This means that these tiles are placed in a region where only a few GCP have correlated with the tile. Hence it means that the tile's area is not covered by many GCP in the L1C GCP GRI. Hence the results for these red dots are not really trustable.

The scatter plots per continents are presented hereafter:



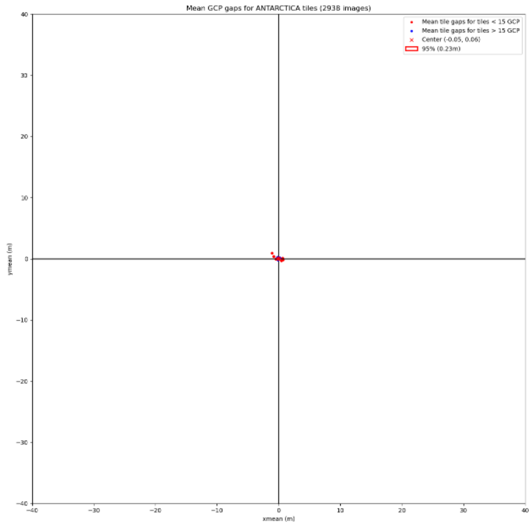


Figure 4. Scatter Plots of shifts over each continent between L1C Tile and L1C GCP coming from the same L1B datastrip

Note: In Europe, a group of at least 6 red points is visible on the bottom right, it has been verified that they were not coming from the same DS and this is pure coincidence that they are gathered with a pattern. However, those are red points and have less than 15 matching GCP (even less than 5, most of the time 1 or 2).

This can be summarized in the table below:

Table 1: Mean shifts between L1C Tile and L1C GCP coming from the same L1B datastrip for the world and each continent

Area	shift (CE95)
WORLD	0.38 m
AFRICA	0.41 m
ANTARTICA	0.23 m
ASIA	0.32 m
AUSTRALIA	0.21 m
EUROPE	0.31 m
NORTH_AMERICA	0.38 m
SOUTH_AMERICA	0.28 m

From this table, we can see that the global coherence of both Multi-Layer L1C GRI and L1C GCP GRI is very good (0.38 m for the WORLD).

4.2 Relative coherence of the GRI

This section relates results of the comparison of a L1C images from the Multi-layer L1C GRI versus L1C GCP chips that cover the Tile but coming from different datastrip. Results from previous section (4.1) are expected to be very good, if results differ with this other comparison, they will represent the global consistency of the Multi-Layer L1C GRI (which is also the consistency of the Multi-Layer L1B GRI).

Chips coming from the same datastrip are not used in this comparison, not to bias results. However, the limitation is that for some Tiles, there might be no chip left to correlate with, hence, the relative coherence is only computed on areas where there are several chips. Therefore, this really represents the relative consistency of the L1C GCP GRI. And as the previous section proved that results are very close, this relative consistency can be transposed to the Multi-Layer L1C GRI.

The following scatter plots presents the result of the comparison for the world:

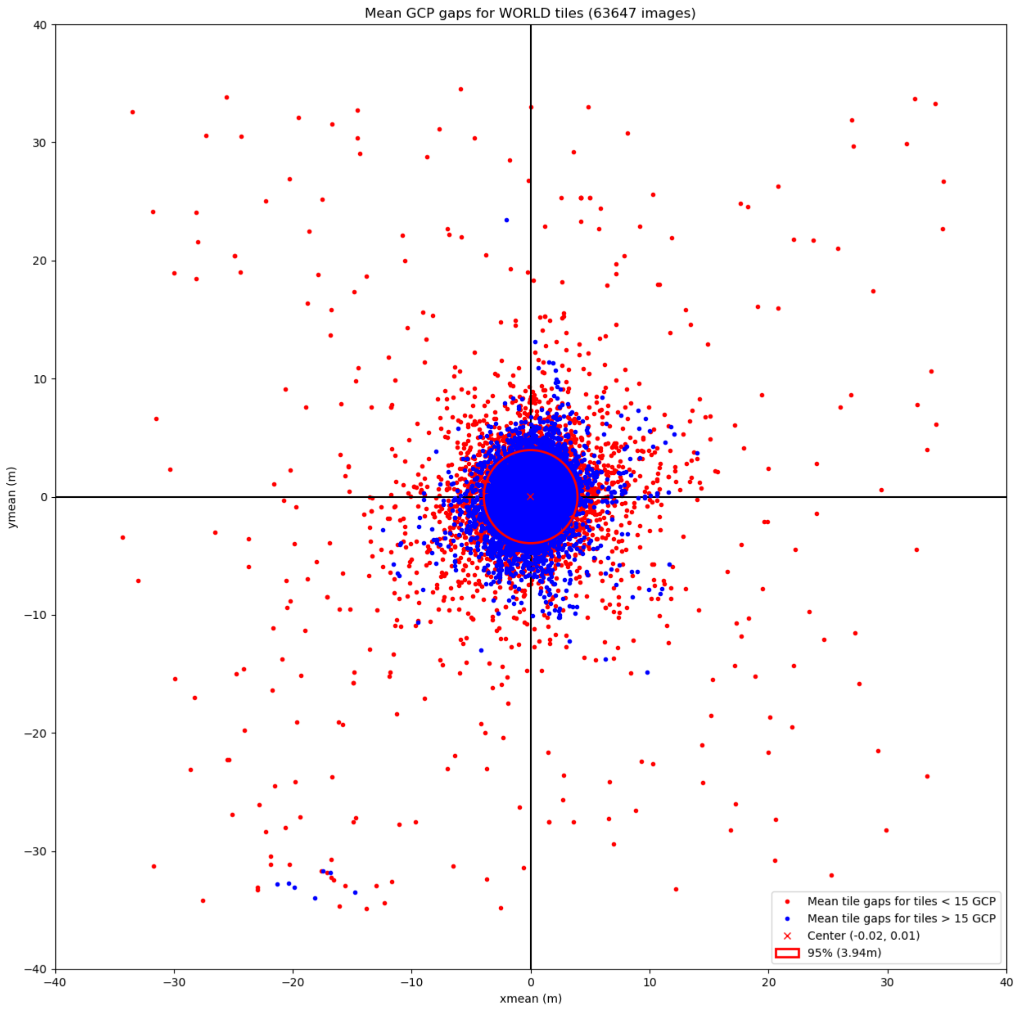
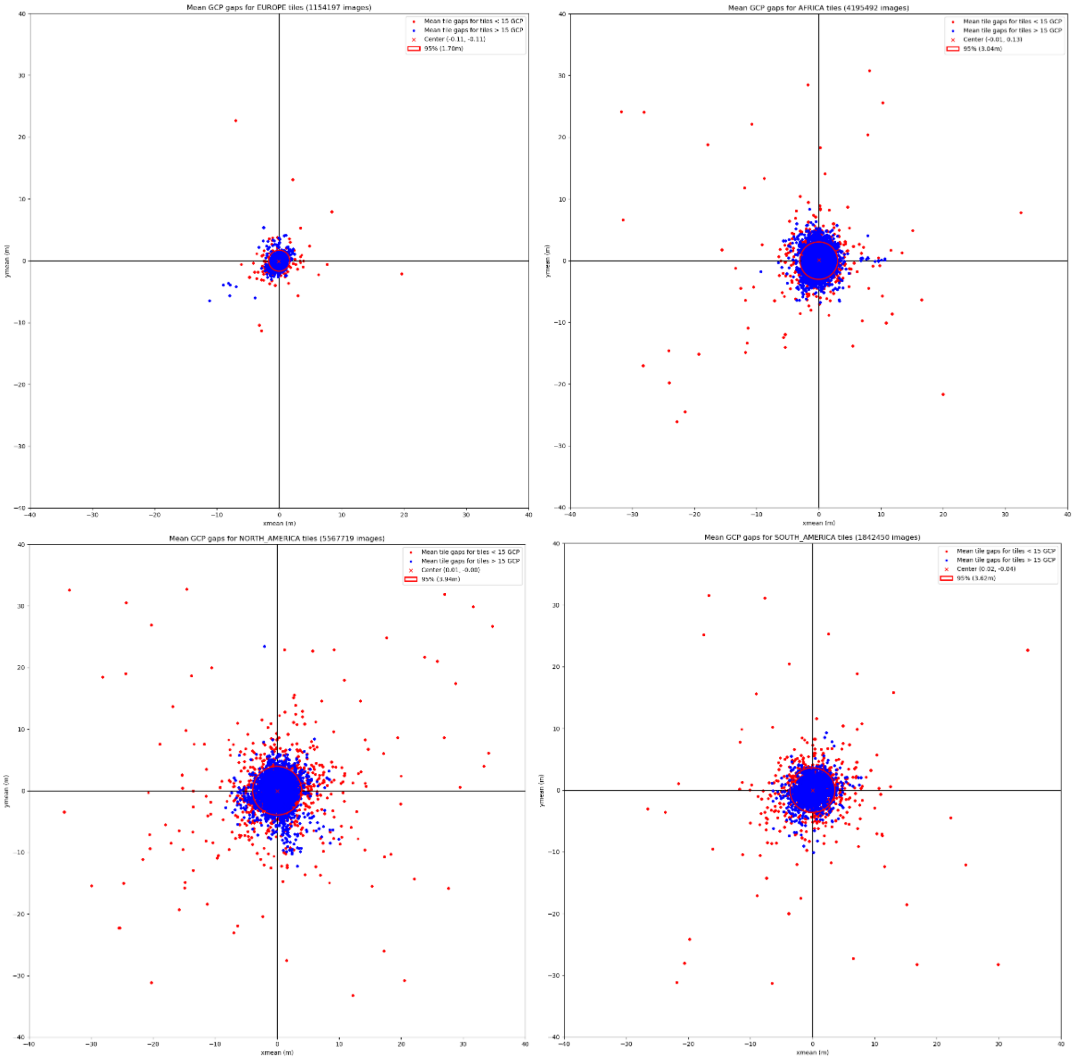


Figure 5. Scatter Plot of shifts over the World between L1C Tile and L1C GCP coming different L1B datastrips

As in previous section, red dots represent tiles for which less than 15 GCP have been found. This means that either these tiles are placed in a region where only a few GCP exists or that the L1C tile itself is not suited for correlation because it is very cloudy for instance. In both cases the results for these red dots are not trustable and meaningful.

And here are the scatter plots per continents:



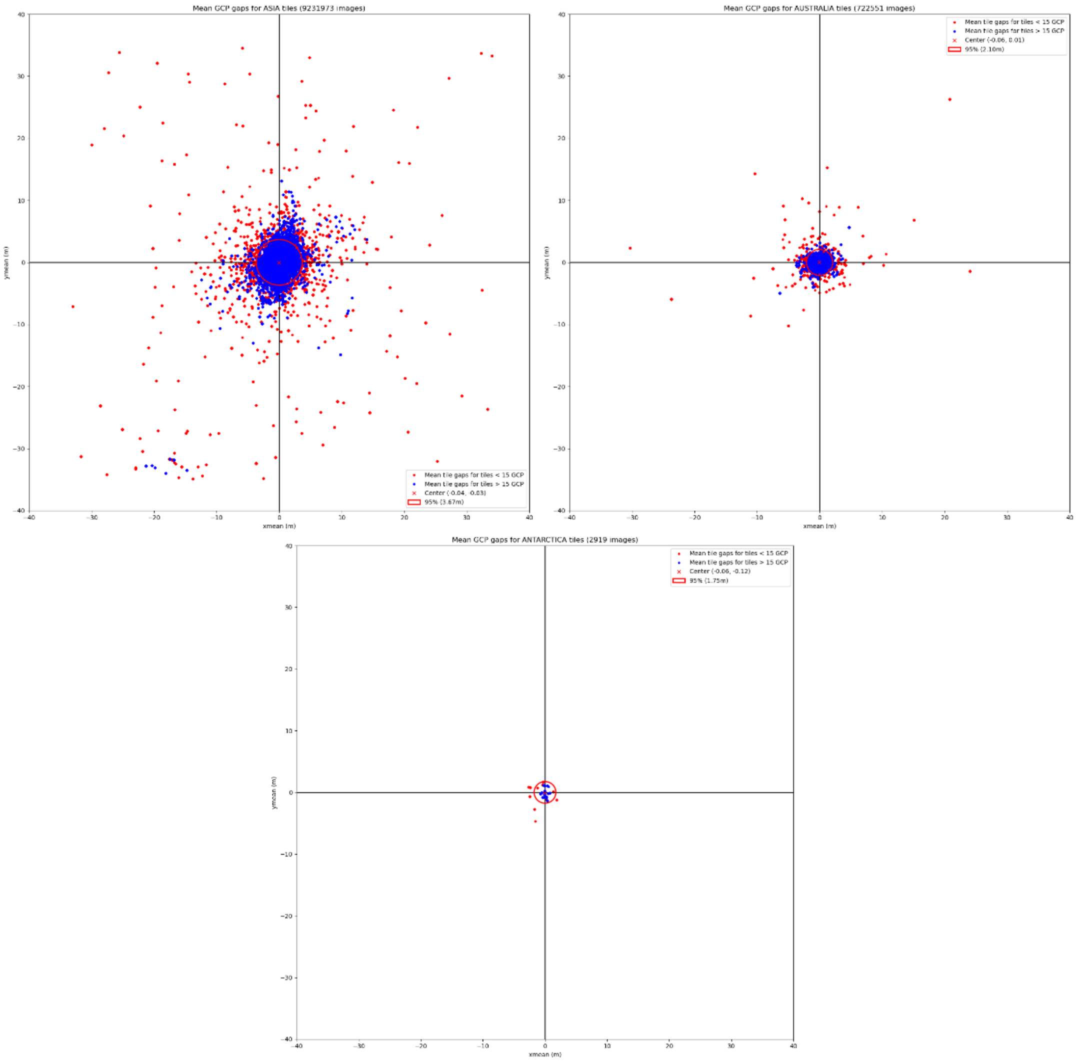


Figure 6. Scatter Plots of shifts for each continent between L1C Tile and L1C GCP coming from different L1B datastrips

This can be summarized in the table below:

Table 2: Mean shifts between L1C Tile and L1C GCP coming from different L1B datastrips for the world and each continent

Area	shift (CE95)
WORLD	3.94 m
AFRICA	3.04 m
ANTARTICA	1.75 m
ASIA	3.67 m
AUSTRALIA	2.10 m

Area	shift (CE95)
EUROPE	1.70 m
NORTH_AMERICA	3.94 m
SOUTH_AMERICA	3.62 m

As expected, results are not as good as in previous section but still very good as the consistency of the GRI in itself is at still 3.94 m CE95. This reinforces the already pointed out fact that all GRI (Multi-Layer L1B GRI, Multi-Layer L1C GRI, GCP GRI) shall be used with a consequent set of items (datastrips, Tiles, Points), taking advantage of the statistical effect, rather than considering items independently.

Regarding the inner coherence, two maps could be showed to illustrate it too:

- ✓ For each Tile with several overlaps, colour it depending on the minimal distance computed (between an overlap Tile versus all the GCP that are not coming from the same datastrip): Figure 7
- ✓ For each Tile with several overlaps, colour it depending on the maximal distance computed (between an overlap Tile versus all the GCP that are not coming from the same datastrip): Figure 8

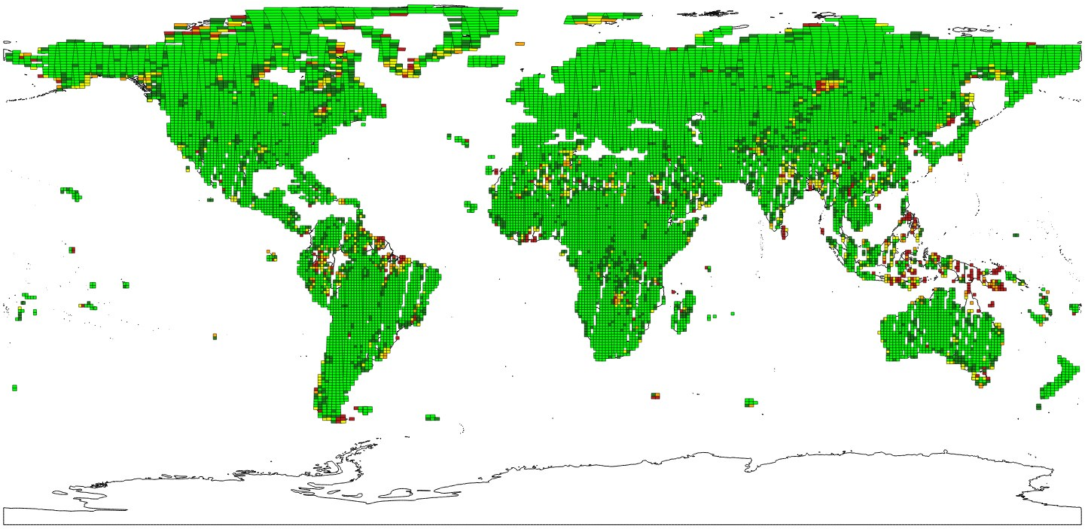


Figure 7. Minimal inner consistency of the ML L1C GRI versus L1C GCP GRI (green<1m to red >4m)

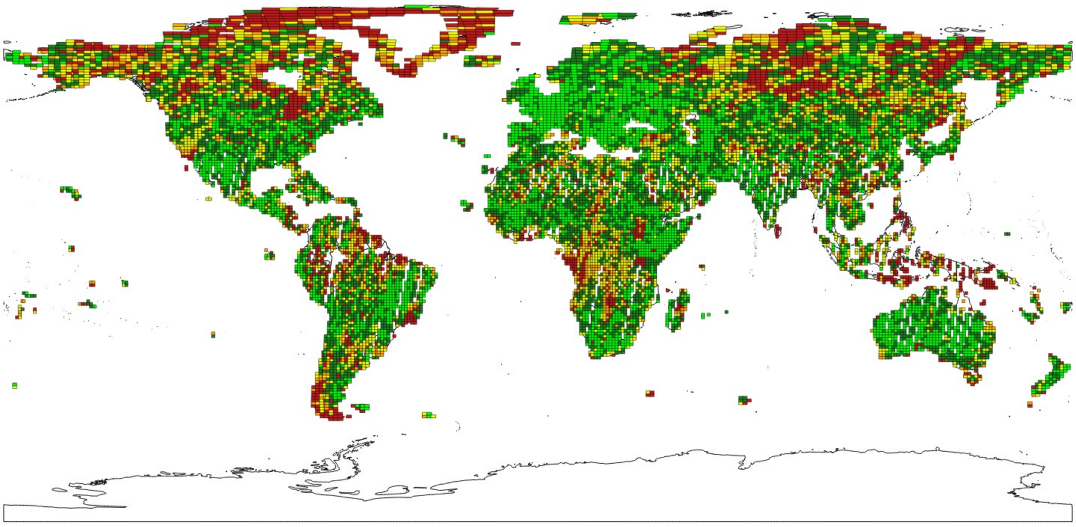


Figure 8. Maximal inner consistency of the ML L1C GRI versus L1C GCP GRI (green<1m to red >4m)

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

In figures above, the analysis is however limited as it is computed with GCP coming from the same GRI (even if not from the same datastrip, so distance between A and B is equal to distance between B and A).

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