INVESTIGATIONS ON THE GLOBAL IMAGE DATASETS FOR THE ABSOLUTE GEOMETRIC QUALITY ASSESSMENT OF MSG SEVIRI IMAGERY

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ABSTRACT:

EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites), an intergovernmental organisation founded in 1986, supplies weather and climate-related satellite data, images and products throughout the year for EU Member States and other users worldwide. The optical Earth Observation satellites launched and operated by EUMETSAT, both current and planned ones, have different spatial, spectral and temporal resolutions; sensor models and acquisition geometries. While the number and the diversity of the satellite missions increase, the requirement of novel methods and up-to-date reference data for geometric accuracy assessment of the imagery also grows. This paper aims at reporting the results of a study investigating the availability for suitable satellite imagery to be employed as reference data for the geometric quality assessment (GQA) of MSG SEVIRI Level 1.5 image products. The reference datasets need to have superior spatial resolution, wide global coverage, and spectral compatibility with respect to the SEVIRI sensor, which has 12 spectral bands with 1 km and 3 km spatial resolutions. The SEVIRI sensor works with whiskbroom principle at a geostationary orbit and collects data at 5 minutes (rapid scan) and 15-minutes (full scan) intervals. Although preliminary investigations on reference data were performed by using images of different satellite sensors during the study, in-depth investigations were performed with MERIS global image mosaic and Landsat imagery. The progress and different problems observed in the images are reported here.

1. INTRODUCTION

Geometric and radiometric characterization and quality assessment of satellite optical imagery are essential for multi-temporal and multi-sensor data fusion; as well as for analysing the quality and usability of their products. The images of optical Earth Observation (EO) satellites operated by EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) have routinely been assessed in terms of geometry and radiometry. The current operational weather satellites of EUMETSAT are Meteosat-8, 9, 10 and 11; Metop-A, B C; Jason-3, and Sentinel-3A and 3B (EUMETSAT, 2020a). The planned future satellites involve geostationary and polar orbiting satellites as well.

The Meteosat Second Generation (MSG) satellites, which are operating in four different geostationary orbits (i.e. Meteosat-8 at 41.5° E, Meteosat-9 at 3.5° E, Meteosat-10 at 9.5° E, and Meteosat-11 at 0°), 36,000 km above the Equator; are among those (EUMESAT, 2020b). Currently Meteosat-11 is the prime operational geostationary satellite; whereas Meteosat-10 is used for rapid scanning service by taking images every 5 minutes over parts of Europe and Africa. It also provides images for Search and Rescue monitoring. Meteosat-9 is gap-filling and back-up spacecraft for both Meteosat-10 and Meteosat-11 for rapid scanning and full Earth scanning, respectively. Meteosat-8 is providing data coverage service for Indian Ocean (EUMESAT, 2020b).

The Spinning Enhanced Visible the InfraRed Imager (SEVIRI) sensors aboard MSG satellites are acquiring images of Earth with 12 spectral channels. The spectral bandwidths range from visible bands to different portions of infrared. The satellites provide imagery of Europe, the North Atlantic and Africa every 15 minutes, for operational use by meteorologists. The products of SEVIRI are fundamental for several meteorological applications and estimation of essential climate variables. Out of the 12 spectral bands of MSG SEVIRI, the High Resolution Visible (HRV) band has 1 km spatial sampling at Sub Satellite Point (SSP), whereas the other eleven bands have 3 km sampling at SSP.

The absolute geometric quality assessment (GQA) of the MSG SEVIRI images is routinely performed by EUMETSAT using a landmark matching approach. The total number of landmarks used for the assessment is in the order of a few hundreds, and they are defined mostly on the shorelines. Due to cloud coverage only a small subset of them are matched on the images using the Normalized Cross Correlation (NCC) operator and the number of the matched points depend on the cloud cover. Another method was proposed for absolute accuracy assessment of SEVIRI HRV Level 1.5 images based on lake matching over Switzerland and parts of neighbouring countries (Aksakal, 2013; Aksakal et al. 2013a, 2013b).

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In the frame of a study initiated by EUMETSAT a new approach for GQA of SEVIRI Level 1.5 images has been developed collaboratively with EUMETSAT, Telespazio SA, France, and Hacettepe University, Turkey. With the developed approach, the absolute location, interband (band-to-band) registration and multi-temporal stability of MSG SEVIRI images can be assessed using dense image matching techniques with sub-pixel accuracy and their suitability for Low Earth Observation (LEO) satellites were investigated in preliminary tests as well. The developed methodology is being implemented in a standalone software, GQA Tool, which is based on open source libraries and Python programming language.

The developed absolute GQA approach is essentially based on comparing reference and search (or working) images using a least squares matching technique in the GEOS (geostationary) projection system. Although the developed methodology is powerful and allows dense matching results (thousands of points depending on the selected band and cloud coverage), it has the main requirement of provision of reference images with superior spatial resolution and geometric accuracy. In addition, a homogenous, global coverage is also needed to assess the full extent of SEVIRI images. For this purpose, a number of freely available image datasets (i.e. Landsat 5-7-8, MERIS, OLCI, Sentinel-2) have been investigated within the study in terms of geometric accuracy, spectral bandwidth compatibility with SEVIRI, image artefacts, geographical coverage, and availability of global mosaics. It must be noted that easy access to the archives was found essential for such studies, since the mosaic production is a time consuming and even exhaustive process; and the results need to be analysed in terms of geometric and radiometric quality by using a number of factors, such as existence of image artefacts, cloud coverage percentage, radiometric differences caused by the time of the acquisition (e.g. seasonal differences), visibility of seamlines in the mosaics, etc.

In this paper, the process of global image mosaics generation for the purpose of performing the absolute GQA of SEVIRI is described and the problems observed throughout the study are defined. Currently, the developed tool can assess the interband, temporal and absolute GQA of SEVIRI Level 1.5 images, and the preliminary tests have been performed for a selection of bands (i.e. HRV, Visible 0.8, Visible 0.6 and Infra-red 10.8). One of the advantages of the developed system is flexibility in terms of reference data, which allows replacement/update of the reference datasets and on-the-fly keypoint generation whenever needed. Thus, the reference data can be updated on a regular or on-demand basis. However, the preparation of such datasets requires detailed investigations and in particular extensive error-analyses. The experiences and key issues for compilation of the reference datasets for the absolute GQA of MSG SEVIRI images are presented in this paper with particular focus on Landsat and MERIS imagery.

2. REFERENCE DATA REQUIREMENTS

2.1. MSG SEVIRI Characteristics

The image acquisition principle of SEVIRI sensor is shown in Figure 1. The images are acquired in whiskbroom fashion, and the focal plane arrangements of the sensor vary in terms of the detector numbers and locations for different bands. The Level 1.5 products are corrected from the raw Level 1.0 image in real-time for all radiometric and geometric effects and georeferenced in the GEOS projection system (Just, 2000; EUMETSAT, 2017). The spectral band definitions of SEVIRI sensor are provided in Table 1.

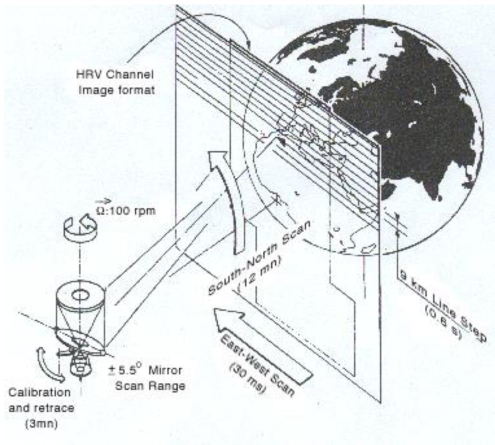

Figure 1. SEVIRI Earth imaging principle (EUMETSAT, 2017).

Channel ID	Absorption Band/ Channel Type	Spectral Bandwidth (m)
HRV	Visible/High Resolution	0.6 to 0.9
VIS 0.6	VNIR/Core Imager	0.56 to 0.71
VIS 0.8	VNIR/Core Imager	0.74 to 0.88
IR 1.6	VNIR/Core Imager	1.50 to 1.78
IR 3.9	IR/Window Core Imager	3.48 to 4.36
IR 6.2	Water Vapour/Core Imager	5.35 to 7.15
IR 7.3	Water Vapour/Pseudo-Sounding	6.85 to 7.85
IR 8.7	IR/Window Core Imager	8.30 to 9.10
IR 9.7	IR/Ozone Pseudo-Sounding	9.38 to 9.94
IR 10.8	IR/Window Core Imager	9.80 to 11.80
IR 12.0	IR/Window Core Imager	11.00 to 13.00
IR 13.4	IR/Carbon Dioxide Pseudo-Sounding	12.40 to 14.40

Table 1. SEVIRI band characteristics (EUMETSAT, 2017).

The geometric quality criteria provided by EUMETSAT (2007) is better than 3 km at SSP for the relative and absolute accuracies and 1.2 km for relative accuracy. All bands have 3 km ground sampling distance (GSD) at SSP, except the HRV band, which has 1 km GSD and operates at the visible portion of electromagnetic spectrum. Image examples of HRV, VIS0.8 and IR10.8 bands are shown in Figure 2.

2.2. Requirements for Absolute GQA of SEVIRI

The absolute geometric quality (i.e. georeferencing) of a sensor is assessed using external reference data. The reference data should have superior resolution and accuracy with respect to the data to be assessed, and in practice reference data with at 3-5 times or even higher accuracy should be sought (Gruen and Kocaman, 2008). The evaluation method (e.g. point-wise, regional, or global) depends on the density, distribution and other characteristics (e.g. 2D and 3D coordinates, availability of earth surface reflectance data in different spectral bands, temporal characteristics, etc.) of the reference data.

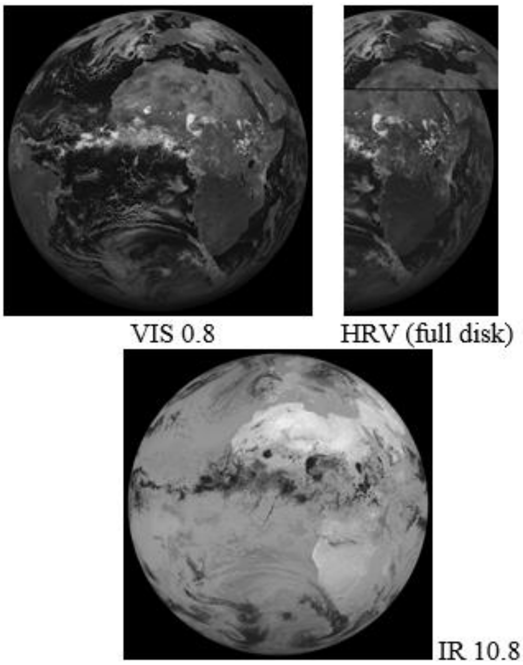

Figure 2. Image examples of HRV (full disk), VIS0.8 and IR10.8 bands acquired on July 1st, 2018, at 12:00 UTC.

In this study, the absolute GQA of MSG SEVIRI images were assessed with respect to orthoimages due to low spatial resolution of the datasets. In principle, the following qualities were taken into account for the absolute GQA of MSG SEVIRI images by employing the image feature matching methods on the orthorectified satellite images:

- The radiometric and geometric quality of the reference data is a key factor in the GQA, and the results can be effected by image artefacts, clouds, systematic errors in radiometry and geometry, etc. This issue is particularly analysed here.

- Sufficient textural information for different matching window must be available to extract high quality keypoints (i.e. feature points or ground control points).

- The keypoints must be usable for different spatial resolutions (e.g. 1 km and 3 km).

- The spatial distribution of the keypoints are required to be homogeneous over land areas and cover the full disk extent.

- For optimal keypoint extraction and matching, spectral band compatibility should also be taken into account.

- If possible, seasonal differences need to be covered over the area to assess, for example by using summer and winter images.

- The image product level and the projection system definitions may also be important. Image re-projection and resampling (or warping) can yield to radiometric and geometric artefacts after the transformation depending on the warping method and the image interpolation algorithm.

3. REFERENCE DATA PRODUCTION

The initial reference data preparation efforts in the project involve Landsat images, including the Global Land Survey (GLS) dataset, Sentinel-2 images, and the MERIS images. The list of all datasets considered for absolute GQA are provided in Table 2. Their advantages and disadvantages are presented in Table 3. The sensor specifications and the issues with each dataset, except for the Sentinel-2 images, are explained in the following sub-sections.

Name	Source	Band	Type	Tested
Landsat GLS	https://earthexplorer.usgs.gov/ (NASA/USGS)	NIR band	L1 products	Europe
MERIS RGB	GAEL consultant, France	Red band	RGB mosaic	World
Sentinel2 cloudless	https://s2map.eu/ (EOX)	Red band	RGB mosaic	World
Sentinel2 L2A	https://scihub.copernicus.eu/ (ESA)	NIR band	L2A products	Europe
MERIS L3	https://www.esa-landcover-cci.org/ (ESA)	RED & NIR bands	L3 products	World

Table 2. Global datasets tested for the purpose of absolute GQA of MSG SEVIRI images.

Name	Status (+: pros; -: cons)
Landsat GLS	(+) Resolution (-) Heavy process (download + mosaic generation) (-) Artefacts in Landsat7 data
Meris RGB	(+) Mosaic ready-to-use (-) Problem with coastlines coming probably from a land mask and leads to geolocation errors (-) Lack of contrast on certain areas (bright areas)
Sentinel2 cloudless	(+) Mosaic ready-to-use (-) Degradations due to jpeg compression (-) Lack of contrast on certain areas (bright areas)
Sentinel2 L2A	(+) Resolution (-) Very heavy process (download & product selection & mosaic generation)
MERIS L3	(+) Mosaic generation process is fast (+) No degradation of the geometry and the radiometry (-) Lack of data in many regions

Table 3. Pros & cons of the investigated global datasets described in Table 2.

Here, MERIS RGB with 260 m x 300 m GSD and Landsat including GLS Dataset with 30 m GSD have been selected for detailed assessment due to their resolution and accessibility to archives for on-demand production. The global coverage (large spatial distribution) of these datasets are high and they provide sufficient resolution and accuracy for the 2D (planimetric) absolute accuracy assessment. Their temporal resolutions are not comparable with SEVIRI, yet sufficient, since the level of surface changes for 1 km (HRV) and 3 km (other SEVIRI bands) is negligible. However, the investigations with the Landsat dataset presented here cover only over Europe; since MSG full disk investigations were continued with the MERIS datasets after the initial assessments.

3.1. Landsat Data

The Landsat Program was established by a partnership of the United States Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA). The Landsat satellites provide essential and continuous information about the Earth's land surface acquiring space-based images since 1972 (USGS, 2015). Landsat imagery has been used in a variety of application areas such as global change studies, agriculture, forestry, geology, geography, mapping, resource management, water quality, and coastal researches (USGS, 2012). On the other hand, the GLS dataset was designed to provide global orthorectified, cloud-free Landsat imagery supporting researches about global land cover, land cover change, and ecosystem dynamics (USGS, 2009). The datasets have different versions centred in different years (e.g. 2000, 2005, 2010, etc.), and the orthorectified images from the most recent one (i.e. GLS2010) were utilized here since minimum cloud coverage was ensured. GLS2010 relies on Landsat 4-5 and 7 images.

The geometric accuracy performances of Landsat data have been published by various studies. For Landsat 5, an RMSE better than 50 meters can be assumed (Tuecker et al., 2004). For Landsat 7, 30–40 meters (1σ) was reported by Storey et al. (2008). Regarding Landsat 8, 1.66 m accuracy (CE90) has been obtained according to ESA Landsat 8 Level 1 Product Performance Cyclic Report (ESA, 2016). The GLS data, which is a global orthomosaic produced in a collaboration between USGS and NASA using a combination of Landsat 7 ETM+ and Landsat 5 TM data acquired in 2008-2012, have 1 pixel (30 m) or better RMSE as reported by USGS (GLS, 2020) and Gutman et al. (2013). Thus, the geometric accuracies of the used products were found sufficient for the purposes of the study.

The initial tests with Landsat mosaic generation were performed over Europe with GLS2010. Band 4 of Landsat 4-5-7 were used to create the visible image mosaic, and Band 6 was employed for creating the infrared image mosaic. However, in some areas, GLS2010 data were not available and therefore these parts were filled with Landsat 8 data (Band 4 for visible and Band 5 for infrared). On the other hand, it was observed that Landsat 8 Band 5 was not included in some products, therefore this band was also replaced either with Band 4 or with Band 6 in those areas (depending on the radiometric similarity in the area). The spatial and spectral properties of Landsat 4-5 TM, Landsat 7 and Landsat 8 are given in Tables 4-5-6, respectively. In the Tables, the Bands used for visible and infrared image mosaics are marked with blue and red, respectively.

Figure 3 shows the colour difference issue between the GLS2010 products used in the mosaic. As the first attempt, histogram equalization was applied to the mosaic to avoid the colour differences but was not found satisfactory (Figure 4). Secondly, a linear stretching approach was applied for this purpose and an improved product could be obtained. The radiometrically enhanced mosaics used for the absolute GQA of visible and infrared bands of MSG SEVIRI are presented in Figure 5. Still, radiometric differences between the neighbouring products can be observed, and examples are provided in Figures 6-8.

The Landsat 5 and 7 images in GLS dataset also suffer from the striping problem at the image borders. Examples are given in Figure 9 for Landsat 5 Band-4; and in Figure 10 for Landsat 7 ETM+ Level-1 Band 5 data. The stripes cause false texture and features in the matching process.

Spectral Band	Wavelength (µm)	GSD (m)
Band 1	0.45-0.52	30
Band 2	0.52-0.60	30
Band 3	0.63-0.69	30
Band 4	0.76-0.90	30
Band 5	1.55-1.75	30
Band 6	10.40-12.50	120 (30)
Band 7	2.08-2.35	30

Table 4. Landsat 4-5 TM spectral band characteristics (USGS, 2020).

Spectral Band	Wavelength (µm)	GSD (m)
Band 1 - Blue	0.45-0.52	30
Band 2 - Green	0.52-0.60	30
Band 3 - Red	0.63-0.69	30
Band 4 - NIR	0.77-0.90	30
Band 5 - SWIR 1	1.55-1.75	30
Band 6 - TIR	10.40-12.50	60 (30)
Band 7 - SWIR 2	2.09-2.35	30
Band 8 - Pan	.52-.90	15

Table 5. Landsat 7 ETM+ spectral band characteristics (USGS, 2020).

Spectral Band	Wavelength (µm)	GSD (m)
Band 1 - Coastal / Aerosol	0.43-0.45	30
Band 2 - Blue	0.45-0.51	30
Band 3 - Green	0.53-0.59	30
Band 4 - Red	0.64-0.67	30
Band 5 - Near Infrared (NIR)	0.85-0.88	30
Band 6 - SWIR 1	1.57-1.65	30
Band 7 - SWIR 2	2.11-2.29	30
Band 8 - Panchromatic	0.50-0.68	15
Band 9 - Cirrus	1.36-1.38	30
Band 10 - TIRS 1	10.60-11.19	30
Band 11 - TIRS 2	11.50-2.51	30

Table 6. Landsat 8 spectral band characteristics (USGS, 2020).

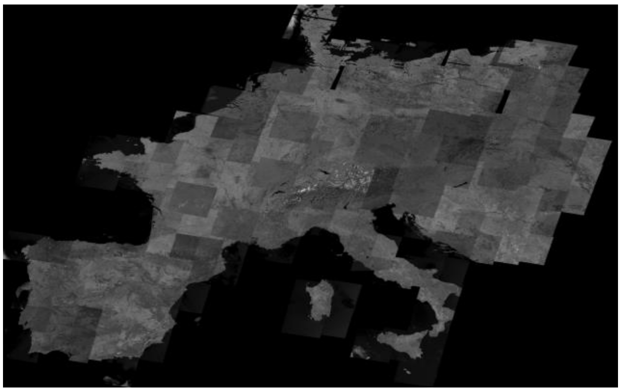

Figure 3. Color adjustment issue observed in Landsat visible image mosaic generated from Landsat 8 and GLS2010 data.

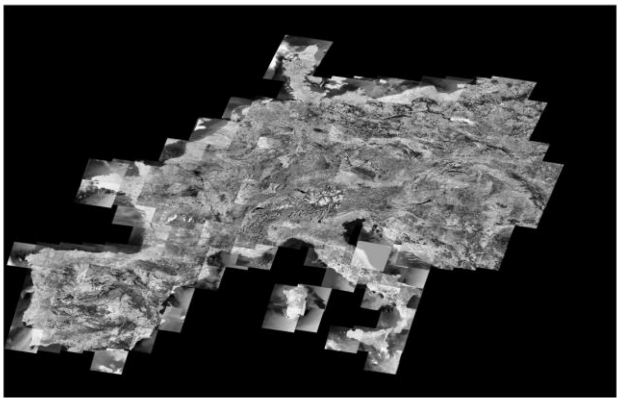

Figure 4. Histogram equalized Landsat visible image mosaic.

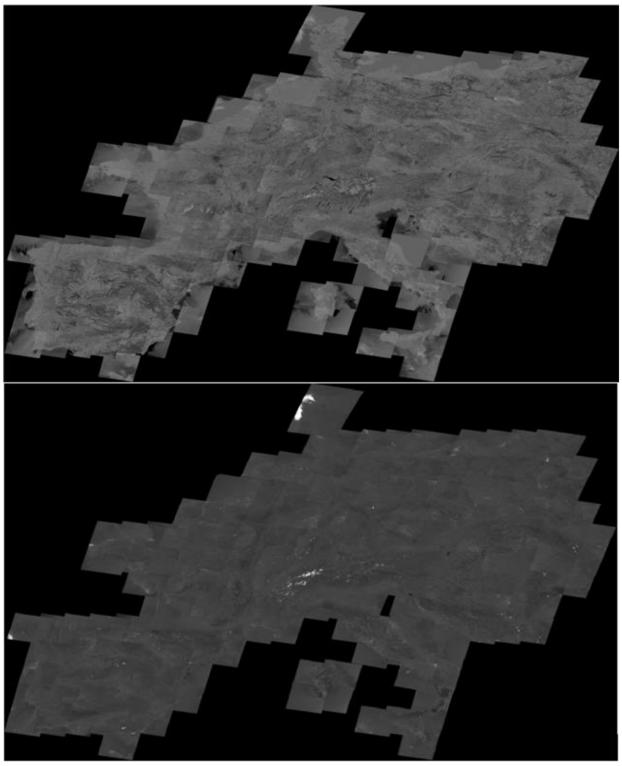

Figure 5. Radiometrically enhanced (linearly stretched) Landsat mosaic comparable with SEVIRI VIS0.8 band image (above) and with SEVIRI IR10.8 band image (below) over Europe.

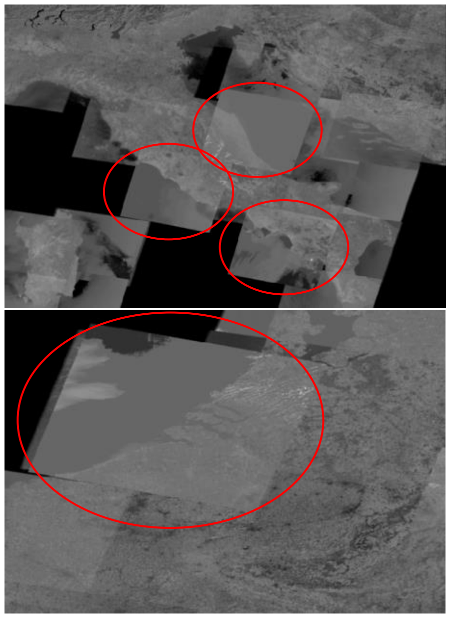

Figure 6. Zoomed views to radiometric differences between Landsat 7 and 8. Landsat 5 and 7 Band 4 together with Landsat 8 Band 5 images were used for mosaicking process.

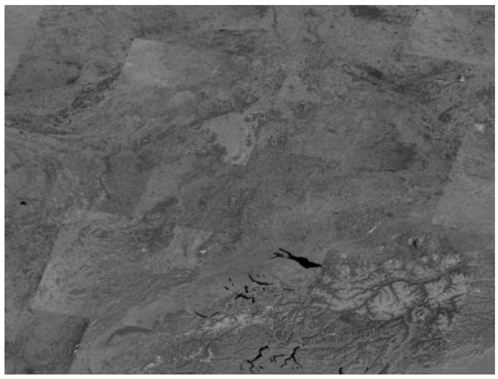

Figure 7. A part of Landsat visible image mosaic over central Europe. The seamlines and the radiometric differences between the Zurich and Leman lake are visible in the mosaic.

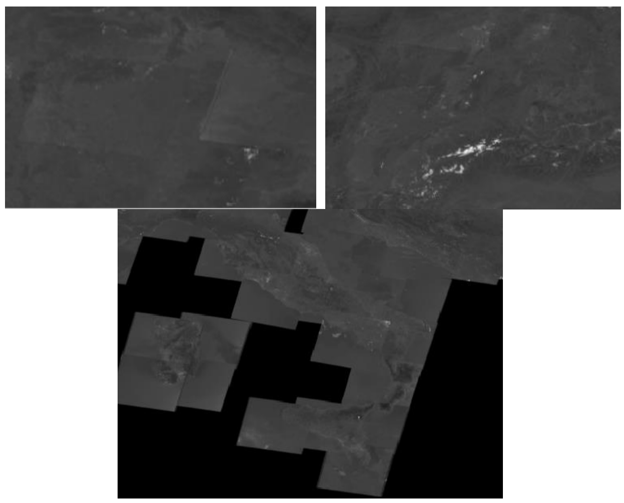

Figure 8. Zoomed views of Landsat IR (infrared) mosaic over different parts of Europe.

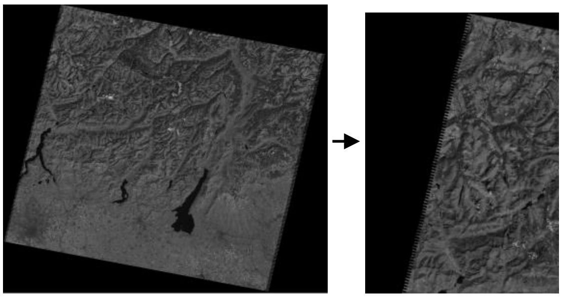

Figure 9. Example of striping error in Landsat 5 Band 4 data visible at the image borders.

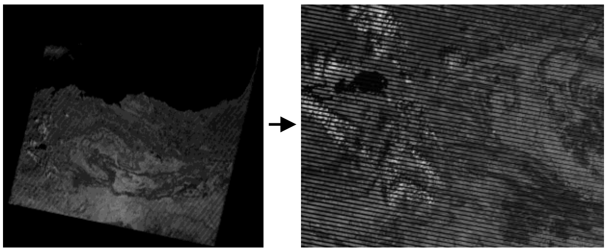

Figure 10. Example of striping in Landsat 7 ETM+ Level-1 Band 5 data.

3.2. MERIS Data

The Medium Resolution Imaging Spectrometer (MERIS) was one of the primary instruments on-board ESA's Envisat-1, which was launched in March 2002. MERIS acquires images with pushbroom principle in 15 programmable spectral bands. The instrument operates at 260 m x 300 m (full) and 1200 m (reduced) spatial resolutions with a swath width of nearly 1150 km. The main task of MERIS is monitor the ocean colour, but it is widely used for a global environmental monitoring system in the European scientific community (NASA, 2020). The imaging principle of MERIS is provided in Figure 11. The spectral band specifications are given in Table 7.

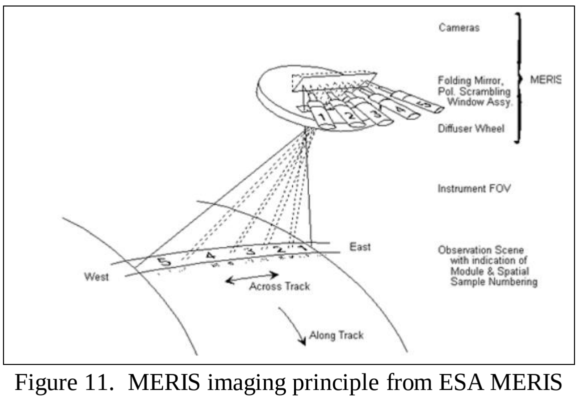

Figure 11. MERIS imaging principle from ESA MERIS Product Handbook (MERIS, 2011).

77 m of total RMSE error was obtained from a number of geographically distributed MERIS GlobCover Orthotectified datasets by Bicheron et al. (2011). Initial tests were performed with the MERIS RGB mosaic obtained from GAEL consultant, France. However, several problems were observed with the image such as very bright areas and geometric problems at the coastlines. On the other hand, matching with the MERIS RGB (only red band was used) was found successful in terms of the number and the distribution of the keypoints over the globe. Therefore, a second attempt was made to produce own MERIS L3 mosaic generation using the ESA Climate Change Initiative (CCI) archives (ESA, 2020). The MERIS products (Level 1B, Level 2 and Level 3) are radiometrically corrected and resampled on a path-oriented grid level. The Level 3 products are weekly synthesis of more than one MERIS products. Here, all possible MERIS images in the archive (5 months of data per year) were mosaicked by using the median values of each pixel in the overlapping areas. Mosaics of every MERIS band could be produced on demand. Here, Bands 7, 12 and 13 were generated and found suitable for using as reference with the SEVIRI images. The MERIS mosaics have full global coverage, and the Band 7 mosaic projected into MSG projection system with 1 km resolution is shown in Figure 12.

MERIS Channel	Band Centre (nm)	Bandwidth (nm)
1	412.5	10
2	442.5	10
3	490	10
4	510	10
5	560	10
6	620	10
7	665	10
8	681.25	7.5
9	708.75	10
10	753.75	7.5
11	760.625	3.75
12	778.75	15
13	865	20
14	885	10
15	900	10

Table 7. MERIS spectral bands (MERIS, 2011).

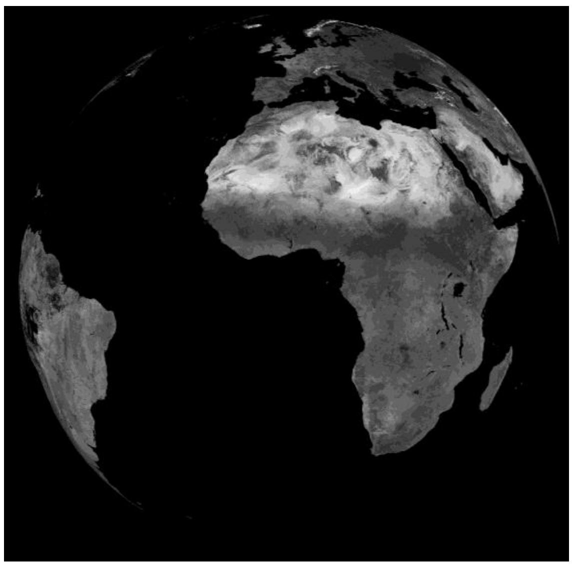

Figure 12. Synthetic SEVIRI image build with MERIS L3 Band 7 data (more than 50 products).

4. DISCUSSION

The produced reference datasets were evaluated for their relative geometric accuracy. A comparison of shifts computed between the produced Landsat Europe mosaic, the MERIS

RGB (red band) and the MERIS L3 mosaics (cropped for the same area) are provided in Table 8. A number of joint feature points were used for each comparison. The tests were performed at different resolutions (GSDs) during the preliminary investigations. Large shifts were observed with the MERIS red band mosaic as can be seen in the Table. The shifts vary over different regions, which is also reflected in the standard deviations. A visual comparison between the MERIS RGB mosaic (red band only) and the MERIS L3 mosaic over Port Gentil area, Gabon, is shown in Figure 13. Figure 14 shows the radiometric differences between the reference mosaics and the SEVIRI HRV band image over Sicilia, Italy. All reference datasets were transformed into MSG projection system and downsampled to 1 km to match the HRV image resolution (Figure 14) and also 3 km for the other bands.

Image Pair	**Number of points**	**East shift & std.dev.**	**North shift & std.dev.**
Landsat visible - MERIS RGB mosaic (matched at 3 km GSD)	~2200	5.25 km 0.75 km	2.25 km 1.30 km
Landsat visible Europe - MERIS L3 B7 (matched at 300 m GSD)	~8500	500 m 145 m	500 m 75 m

Table 8. 2D global mean shifts and standard deviations between the Landsat Europe visible mosaic, MERIS red band mosaic and MERIS L3 B7 mosaic datasets over Europe.

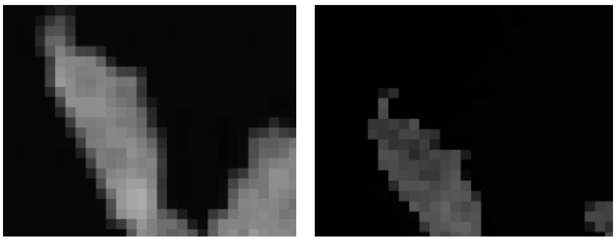

Figure 13. 2D displacement observed in MERIS RGB (red band only, left) and MERIS L3 synthesis (B12, right) over Port Gentil area, Gabon, (zoomed view at MSG projection, 1 km GSD).

5. CONCLUSIONS AND FUTURE WORK

This study was carried out as a part of new GQA Tool development study for EUMETSAT satellite image project. While the tool is developed mainly with the main idea of image matching based on textural features, suitable global imagery to be used as reference for day and night images was required. The investigations with the MSG SEVIRI Level 1.5 HRV, visible 0.8 and infrared 10.8 images have shown that Landsat and MERIS datasets can provide sufficient level of geometric accuracy and spectral compatibility. However, processing of Landsat images has shown that a global cloud-free mosaic is possible by combined use of Landsat 4-5, 7 and 8 data, which cause radiometric differences between neighbouring images and visible mosaic seamlines. In addition, radiometric artefacts such as striping or missing bands are also occasionally present.

After the initial tests with an MERIS RGB global mosaic, this dataset was also found suitable for the purposes of the study. Recent MERIS L3 weekly synthesis data provided by ESA CCI service were used for reference image generation. The resolution, geometric accuracy, and spectral band availability of the MERIS L3 mosaic is also sufficient for the GQA of MSG SEVIRI.

While the GQA Tool also aims at assessing EUMETSAT LEO (Low Earth Observation) imagery, reference data with higher spatial resolution are also required. Sentinel-2 archives have the potential to satisfy this aim.

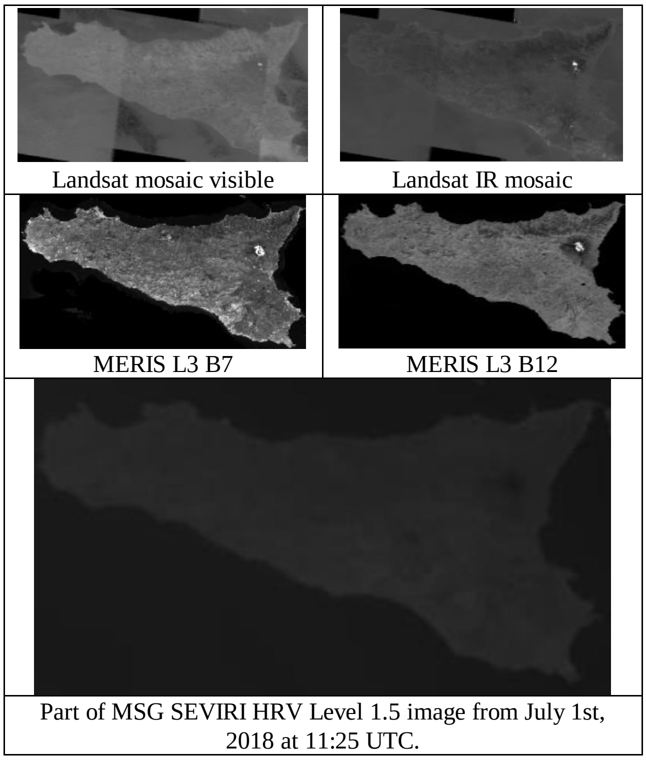

Figure 14. Parts of the produced reference data in GEOS projection and the SEVIRI HRV image over Sicily, Italy.

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