Positional Accuracy of the RapidEye Image Products

Version 1.0 | April 2015

EXECUTIVE SUMMARY

As with most optical satellites, the positional accuracy of RapidEye imagery products is driven by the quality of the ground control points and terrain models used during the processing of the raw data. Consistent global sources for high-accuracy control points are virtually unknown and regional datasets of this quality are usually prohibitively expensive when found. These problems have not deterred BlackBridge from working continuously to improve the quality of control sources used to process the imagery. As of 2015, BlackBridge has created the most accurate global reference dataset for high-resolution imagery, thus allowing for the standard production of RapidEye image products with the best possible locational accuracy across the world to date.

Designed and built to support the orthorectification of RapidEye satellite imagery on a global scale, Global Reference 2.0 ground control dataset leverages some of the most accurate datasets available worldwide. Over 86% of the more than 500,000 ground control points (GCPs) in the dataset have been derived from 50 cm resolution DigitalGlobe WorldView-1/2/3 and GeoEye-1 satellite imagery. The remaining 14% has been extracted from very high-resolution (VHR) airborne imagery (Continental US, Mexico and several European countries) with resolution under 1 m and from the AGRI (Australian Geographic Reference Image) dataset with 2.5 m resolution. This dataset is suitable for the correction of other high- or moderate-resolution image sources.

In support of the implementation of the BlackBridge Global Reference 2.0 dataset, an internal verification has been performed with independent checkpoints over 15 different locations worldwide with a total of 45 level 3A products. Additional verification tests have also been conducted on level 3B and RapidEye Mosaics (level 3M) products. The results of this testing show that the Root Mean Square Error (RMSE) was found to be under 7 m for 80% of the test level 3A products and always under 10 m. The level 3B and 3M products show that 70% are under 8 m and the remainder under 10 m. These results, along with BlackBridge's experience processing thousands of ortho-images every day, confirm that Global Reference 2.0 allows for the production of orthorectified imagery with positional accuracy under 10 m RMSE on a global scale.

Introduction

The purpose of this white paper is to present the results of the testing conducted on RapidEye orthorectified imagery products (Levels 3A, 3B and 3M) related to the implementation of BlackBridge's Global Reference 2.0 dataset. As part of this, a brief description of positional accuracy and the terms surrounding it is included. This is followed by a description of the Global Reference 2.0 dataset and then the report results achieved over a number of test sites distributed across continents and land cover types.

All orthorectified RapidEye imagery products (Levels 3A, 3B and 3M) are corrected using GCPs and Digital Elevation Models (DEM) by means of a rigorous camera model and the information provided by a number of on-board sensors (including a GPS receiver and a star tracker). The positional accuracy of imagery products is driven by the quality of the GCPs and DEMs used to process the raw data. With survey grade GCPs and accurate DEMs, RapidEye orthorectified imagery can achieve a high positional accuracy regardless of location, look angle, or terrain.

Since the start of operations in 2009, all RapidEye imagery products have been cataloged and controlled using GCPs derived from a number pre-existing datasets. Areas over the continental United States have always been controlled using National Agriculture Imagery Program (NAIP) imagery from the USDA, whereas areas outside of the continental United States have used a number of different datasets over time. Initially, GCPs outside of the US were derived from the Landsat GeoCover 2000 dataset (published global accuracy of 50 m CE90 or better), but most of these were replaced with points derived from the newer Landsat GLS 2000 dataset (published global accuracy of 30 m CE90 or less). From this point, BlackBridge's commitment to improving the quality and usability of its image products led to the creation of the Global Reference 2.0 dataset starting in 2012.

While the sources for ground control have been evolving, so have the sources of elevation data used in orthorectification. Initially, a corrected version of the 90 m Shuttle Radar Topography Mission (SRTM) dataset or coarser equivalent was used during processing. This 90 m SRTM dataset was later replaced with an enhanced 30 m version, which was then replace by the current and more accurate NEXTMap World 30 dataset from Intermap.

Positional Accuracy

What is positional accuracy?

The positional accuracy of 2-dimensional geospatial data, like satellite imagery, is the value representing the positional difference between the image and the true ground location, or between two images. Accordingly, **absolute** accuracy is the measure of how accurately objects are positioned on the image in respect to their true position on the ground. This true position is defined based on an absolute reference frame, such as the UTM coordinate system, or a satellite image with known and significantly higher positional accuracy than the target image. **Relative** accuracy, on the other hand, is the measure of how two representations of the same object in two data sets (e.g. images) are located relative to each other.

To assess the absolute accuracy, a reference needs to be defined a priori. In what follows, we will use the term *reference* to refer to the dataset having a known spatial accuracy, and *target* dataset or image, the dataset with accuracy that has yet to be determined. In the case of relative accuracy, there is no need to define target and reference datasets, however the words *reference* and *target* will still be used to refer to any of the two images used in the accuracy assessment.

Main factors influencing positional accuracy

The positional accuracy of the RapidEye satellite imagery is limited by the uncertainty related to a number of key system parameters, such as:

- Position of the satellite at the moment of imaging
- Attitude (or orientation) of the satellite at the moment of imaging
- System clock errors
- Atmospheric influences

These errors can be eliminated or minimized by means of calibration procedures. Therefore, the main contributors to positional accuracy errors within the orthorectified image products are typically related to:

- Errors in the ground control point coordinates
- Errors in the point identification (mismarking by an analyst or automated procedure)
- Any error in the DEM used for orthorectification

How positional accuracy is measured

The positional accuracy of satellite imagery is typically measured using a number of statistical parameters that characterize the distribution of the expected errors. The two main methods accepted in the industry are:

- **Root Mean Square Error (RMSE)** - is defined as the square root of the mean squared distances between the objects in the target image and in the reference data set. By definition, the RMSE does not consider any information about the direction of the deviation, but only about its magnitude.

- **Circular Error at 90% confidence (CE90)** - CE90 stands for circular error at 90% confidence, meaning that the radial error of 90% of the measured points will not exceed a previously determined error value. According to the National Standard for Spatial Data Accuracy (NSSDA), the CE90 value is equivalent to the Circular Map Accuracy Standard (CMAS) and is related to the RMSE value if the errors are normally distributed. In that case, CE90 = 1.5175 x RMSE. Alternatively, the CE90 can be empirically calculated for a particular set of data by finding the error value that includes 90% of the points with the lowest error.

Another important statistical method for looking at positional accuracy error is **Mean Error**. Mean Error provides an average deviation in both magnitude and direction of the target image in respect to the reference. Consequently, the total mean error in X and Y directions represents the magnitude of the overall shift of the target image compared to the reference image. This can then be graphed to show the relationship between the accuracy of the product compared to the accuracy of the reference.

Global Reference 2.0

Blackbridge's Global Reference 2.0 is a reference dataset that leverages some of the most accurate datasets available worldwide and is the most current and consistent global control database available.

Over 86% of the more than 500,000 ground control points (GCPs) in the dataset have been derived from orthorectified RapidEye imagery that has been accurately controlled with 50 cm resolution DigitalGlobe WorldView-1/2/3 and GeoEye-1 satellite imagery. The remaining 14% has been extracted from very high-resolution airborne imagery (Continental US, Mexico and several European countries) with resolution under 1 m and from the AGRI (Australian Geographic Reference Image) dataset with 2.5 m resolution. Table 1 provides the source details of the data used to create the GCPs of the dataset.

GCP source	Region	Resolution (m)	Accuracy (RMSE, m)
VHR Aerial imagery	Most countries in the European Union	0.25-0.5	< 3
VHR Aerial imagery	Continental USA, Mexico	1	<6.5
AGRI (ALOS)	Australia	2.5	7.5
VHR Digital Globe Satellite imagery	Rest of the world	0.5	2.3[1]

Table 1: Ground control data sources used to produce Global Reference 2.0.

The vertical component of Global Reference 2.0 is derived from Digital Elevation Models with a post spacing under 30 m globally. Table 2 shows the elevation datasets used for Global Reference 2.0 dataset and for the orthorectification of both the level 3A, level 3B, and RapidEye Mosaic products.

DEM source	Region	Post Spacing (m)	Accuracy (RMSE, m)
USGS NED	Continental USA	10	<3
LINZ	New Zealand	25	6
INEGI CEM 2.0	Mexico	30	7
SRTM	Australia (released by GeoScience Australia)	30	7
Intermap World30	Rest of the world	30	7

Table 2: Digital elevation models used in RapidEye product orthorectification.

[1] Less than 30 degrees off nadir and excluding terrain effects.

Accuracy assessment of RapidEye orthorectified products

Accuracy assessment testing was conducted on both the 3A Ortho Tiles (level 3A products) and the 3B Ortho Takes (level 3B products)/RapidEye Mosaics (level 3M products). The following section describes the test methods and results by product type. In the case of the level 3A products, testing was done to measure not only absolute accuracy of products in respect to the reference data, but also relatively between other tiles of the same location acquired at different dates.

Ortho Tile Product Accuracy (Level 3A)

RapidEye Ortho Tile (level 3A) products are individual 25 km by 25 km tiles of RapidEye imagery orthorectified with GCPs and DEMs, and aligned to a UTM/WGS84 map projection. Image tiles are based on a worldwide fixed grid system with a 500-m overlap between adjacent tiles. Level 3A products include all five spectral bands and have a spatial resolution of 5 m.

Test areas

For testing purposes, 15 test areas were selected in seven countries: USA (Alaska), Brazil, Canada, Germany, Mexico, New Zealand, and South Africa. These areas were selected across a wide range of latitudes, representing a variety of land cover types and terrain characteristics. For each tile or test area, three RapidEye images from different dates (years 2010 to 2014) were selected to represent different viewing geometries ranging from -20◦ to +20◦.

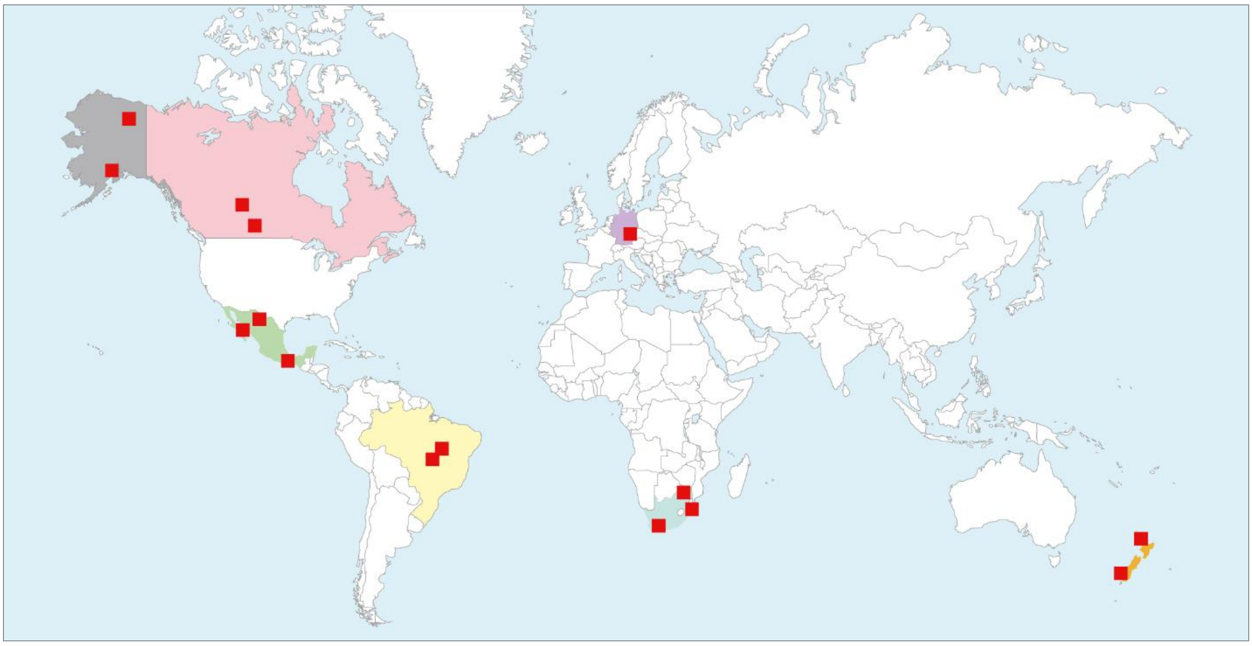

Figure 1: Location of the RapidEye 3A test Tiles.

Absolute accuracy assessment

Absolute positional accuracy testing was conducted using independent reference data as a check of overall product accuracy. This section presents the results of this assessment against this highly accurate reference data from external sources.

For all test sites, VHR airborne orthorectified imagery from well documented public programs was used as reference to assess the positional accuracy of RapidEye images. Table 3 below provides a brief description of the data sources and accuracies of the independent reference data used for each test site.

Country	Reference description	Accuracy
Alaska	USGS digital orthoimagery, 0.3 - 1 m resolution	< 10 m CE90
Brazil	Orthophotos, 0.8 m resolution	< 5 m CE90
Canada	SPOT mosaic from Geobase, 10m resolution	< 10 m CE90
Germany	Orthophotos, 2 m resolution	< 10 m CE90
Mexico	Orthophotos, 2 m resolution	CE90 = 5 m (< 30° off-Nadir)
New Zealand	Orthophotos 1995-1996 and 2000-2001, 2.5 m resolution	< 12.5 m CE90
South Africa	Orthophotos from NGI, S. Africa, 0.5 m resolution	< 10 m CE90

Table 3: Reference data used in the absolute accuracy assessment of RapidEye L3A Ortho Tile data.

The overall RMSE for all the 3A Ortho Tile products in this assessment, taken as a whole, was 5.68 m, based on 6,890 checkpoints. This equates to a cumulative CE90 of 8.62 m for all points. Out of 45 individual products, only 4 were found to have an RMSE higher than 8 m and none exceeded the 10-m (2 pixels) threshold as shown in Figure 2.

Graphing these results against mean error provides additional context to the magnitude of the errors seen in the testing. This is because mean error provides an average deviation in both magnitude and direction of the target image with respect to the reference image, so a value close to zero would indicate that the error observed (RMSE) has, for the most part, a random nature. Inversely, if mean error values are close to the RMSE, then most of the error observed corresponds to a systematic shift. The results of this analysis (see Figure 3) show that most of the images tested showed a substantial contribution of mean error to the overall RMSE, indicating that most of the error measured corresponded to a slight systematic shift of the entire image, rather than a random type of error.

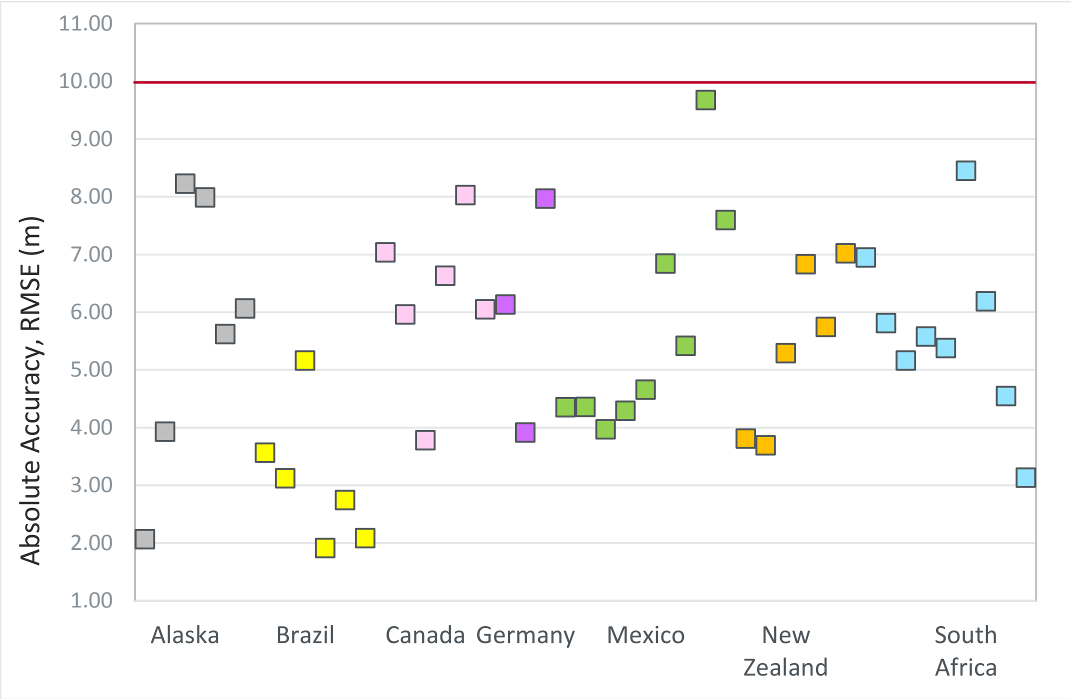

Figure 2: Absolute accuracy of level 3A Ortho Tile images color-coded by location, where each point represents a different image date over the same tile. The red line represents the 10-m RMSE threshold.

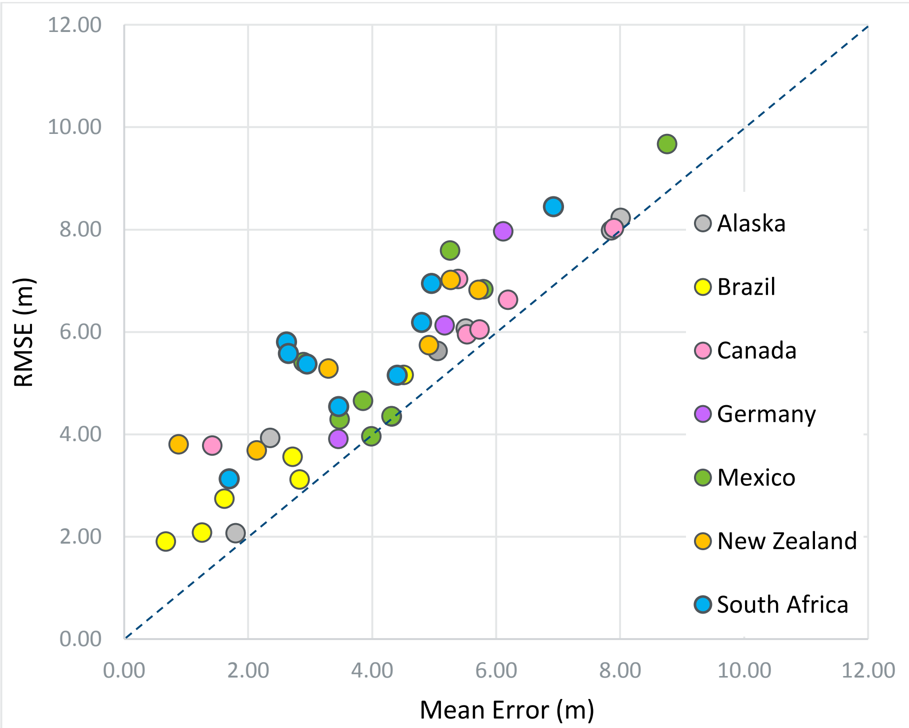

Figure 3: Relationship between absolute RMSE and Mean Error for each image by locations. The diagonal shows the value at which RMSE would be completely due to Mean Error.

Relative accuracy assessment

Relative positional accuracy refers to the spatial accuracy between products acquired at different times over the same location.

The overall relative RMSE for all sites in this study was 5.41 m as shown in Figure 4, based on 20,067 points. Only one image pair exceeded the 10-m (2 pixels) threshold. The CE90 for all points equaled 8.21 m, and the empirical CE90, 8.65 m. The variability shown between image pairs may be due to a combination of factors related to spacecraft view angle, terrain characteristics, or atmospheric conditions. However, a comparison of the absolute accuracy results to the relative accuracy results shows the highest relative inaccuracies occur in image pairs in which one of pair has a low absolute accuracy.

Both the overall absolute and relative accuracies of the level 3A Ortho Tile products, showed a value of around 5 m, indicating that they have a positional accuracy down to one pixel of magnitude.

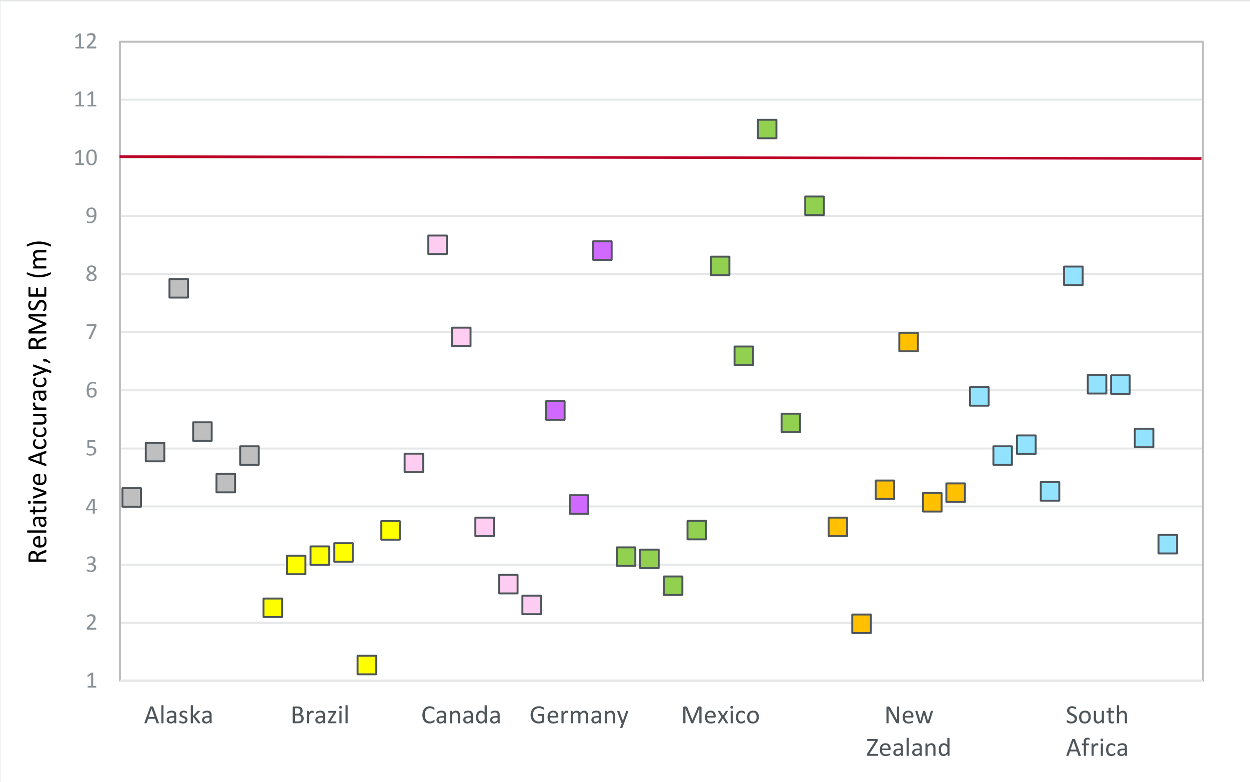

Figure 4: Relative accuracy between level 3A Ortho Tile images color-coded by location. Each point represents an image pair. The red line represents the 10-m RMSE threshold.

Ortho Take and RapidEye Mosaics products accuracy

The RapidEye Ortho Take (Level 3B) product extends the usability of orthorectified RapidEye products by leveraging full image takes and adjusting multiple images together to cover larger areas with fewer files. These products are radiometric, sensor, and geometrically corrected and aligned to a cartographic map projection (UTM/WGS84). These products are orthorectified using GCPs and DEMs, and are bundle adjusted using tie points if multiple products are needed to cover an order area. The Ortho Takes are used to create the RapidEye Mosaics; therefore, the test results presented here apply to both product types.

Test areas

This assessment uses 19 country- or region-wide mosaics (Level 3M) spanning over more than 14 million km^2. All mosaics selected were processed with GCPs derived from VHR satellite imagery and have previously passed a thorough quality control procedure before being released to the public as off-the-shelf products.

Additional details about these and other mosaics can be found at: http://www.blackbridge.com/rapideye/mosaics/index.html.

Figure 5: RapidEye Mosaics used for the accuracy assessment (red areas with dashed-line circle for Hawaii).

Before building the mosaics, the GCPs were separated into two groups. A group containing 75% of all points (control points) was used for the orthorectification process, while the remaining points were used as reference (checkpoints) for the accuracy assessment.

Absolute accuracy assessment

The resulting absolute accuracy of all the regions tested ranged from 3.7 to 9.6 m RMSE with 13 out of 19 mosaics showing a RMSE under 8 m as shown in Figure 6.

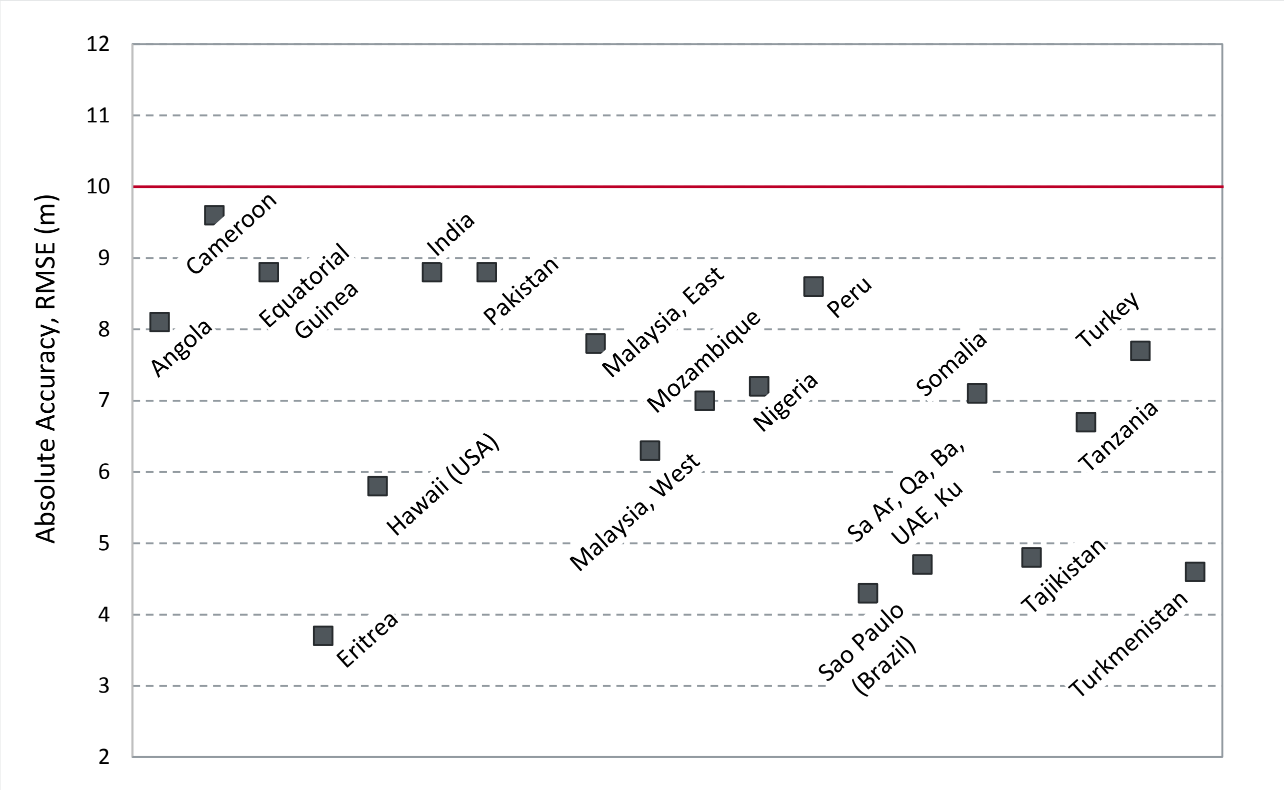

Figure 6: Absolute accuracy of the RapidEye Mosaics. The red line represents the 10-m RMSE threshold

Conclusions

The test results presented in this white paper show conclusively that BlackBridge's Global Reference 2.0 dataset improves the accuracy of the orthorectified RapidEye image products substantially, making them more suitable for many applications that require high positional accuracy. It is further proved that the products will meet or exceed the stated accuracy of 10 m RMSE or less. In reality, most products are better than 8 m RMSE with a relative accuracy close to one pixel. All of this has been achieved with the over 500,000 GCPs of the Global Reference 2.0 dataset derived from very high-resolution satellite or aerial sources. This is a further statement showing that the Global Reference 2.0 dataset is the most current and consistent global control database on the market.

This level of accuracy is a significant improvement and makes RapidEye orthorectified products consistently accurate on a global scale.

For further information on this study or more information on BlackBridge's RapidEye image products, please contact us at support@blackbridge.com.