JRC Scientific and Technical Reports

RapidEye – Initial findings of Geometric Image Quality Analysis

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EUR 24129 EN - 2009

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http://www.jrc.ec.europa.eu/

JRC 56252
EUR 24129 EN
ISBN 978-92-79-14624-4
ISSN 1018-5593
doi:10.2788/52504

Luxembourg: Office for Official Publications of the European Communities

Printed in Italy

RapidEye –
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Objective

This report summarizes the outcomes of the preliminary geometric image quality analysis of the RapidEye 2A and 3A standard image products. The objective of this study is to evaluate the present geometric characteristics of this satellite data, in particular in the context of its suitability for the Common Agriculture Policy (CAP) Control with Remote Sensing (CwRS) Programme.

Acknowledgements

The author would like to thank the RapidEye personel, and in particular Frederik Jung-Rothenhäusler, who kindly provided us with test data. Special thanks go to Scott Douglass for his support in the technical affairs.

Data for testing

Image Data

There are three levels of RapidEye Standard Image Products ('RapidEye Standard Image Product Specifications', January 2009):

- RapidEye Basic Product (level 1B) – path oriented, sensor, on-board spacecraft attitude and ephemeris, and radiometry corrected data, collected in strips up to 1500 km; delivered in 50-300 km by 77 km "processing segments" in NITF format, RPCs in header.
- RapidEye Geo-corrected Product (level 2A): Radiometric, sensor and geometric corrections have been applied to the data. A course DEM is used to correct the image, but no ground control points (GCPs) are used for positional accuracy.
- RapidEye Ortho Product (level 3A) - radiometric, sensor and geometric corrections applied to the data; orthorectified using a DTED Level 1 SRTM DEM or better, and with appropriate ground control can meet an accuracy of 6m 1-sigma (12.7m CE90)[1].

The geometric image quality studies started right after the RapidEye imagery system started to be fully operative. At that point in time (middle March 2009), RapidEye has not verified to what degree the software providers have implemented the necessary additions into their software tools. Therefore, the CID JRC was given two geo-corrected products for testing, namely: RapidEye 2A and 3A image products.

Each 5m-resolution (resampled from the original 6.5m) 16bit geo-tiff files of 25x25km scene size (based on global grid) in standard projection/datum (UTM, WGS 84) is accompanied by its image support data (metadata files)[2]:

- 2009-02-15T111140_RE5_3A-NAC_631251_34774.tif
- 2009-02-15T111140_RE5_3A-NAC_631251_34774_browse.jpg
- 2009-02-15T111140_RE5_3A-NAC_631251_34774_license.txt
- 2009-02-15T111140_RE5_3A-NAC_631251_34774_metadata.xml
- 2009-02-15T111140_RE5_3A-NAC_631251_34774_readme.txt
- 2009-02-15T111140_RE5_3A-NAC_631251_34774_udm.tif

For production of the RapidEye 3A standard product the following auxiliary data is used:

- proprietary SRTM-3 (90m) dataset (with the voids filled and smoothed), and GTOPO30 for areas above 60 degrees North;
- ground control points (GCPs): derived from the Global Landsat Mosaic (typically around 5-7 GCPs per 25kmx25km tile but some tiles are produced with as few as 2 points);

While for production of the RapidEye 2A standard product the following auxiliary data is used:

- a hybrid SRTM global DEM[3] that uses a mix other DEMs in areas not covered by the SRTM. The overall post spacing is 90 meters;

[1] Horizontal accuracy (represented as CE90) is a horizontal measurement on the ground defining the radius of a circle within which an object of known coordinates should be found on an image. The probability of a point in the image meeting the recorded accuracy is 90% for CE90. This parameter is expressed in meters. 12.7m CE90 roughly corresponds to 1-D RMSE of 6.5m.

[2] Technical explanations to the format, layout, content of the metadata etc. can be found in the 'RapidEye Standard Image Product Specifications' document.

- no ground control points (GCPs).

Since RapidEye is willing to re-orthorectify data when better DEMs and GCPs available without any additional charge, we decided to test also this option. We supplied RapidEye with ground and height data of better accuracy than the standard RapidEye auxiliary data. Two additional image products were provided to us:

- 3A tiles created using the high resolution ground control points[4] and DEM[5]: provided by CID.
- the exact same tiles as above, but created with the high resolution GCPs and the standard SRTM DEM.

For both these products 12 ground control points were used for orthoimage generation.

Auxiliary Data

With regards to auxiliary data, the following data was used for RapidEye geometric image quality testing:

- GCPs_DGPS - Set of 20 ground control points (GCPs) of accuracy RMSEx=0.05m, RMSEy=0.05m, RMSEz=0.1m (source: DGPS measurements), however they identification error (on the RapidEye image products) appeared to be at least half of the pixel therefore their overall accuracy in this context is 2.5m (1-D RMSE). These points do not cover the whole area of the RapidEye tiles provided for testing.
- GCPs_ADS40 - Set of 22 ground control points obtained from the ADS40 (Leica Geosystems) digital airborne orthoimage of 0.50m pixel size. The PCI Geomatics automatic image matching algorithm was used to perform this action. The accuracy of these points was also evaluated by this system, and it is 4.292m CE90[6] (horizontal accuracy) and 11.508m LE90 (vertical accuracy). Taking into account the point identification error (on the RapidEye image products), the overall horizontal accuracy of the GCPs_ADS40 can be described as 5-6m (1-D RMSE). These points cover the majority of the RapidEye image tiles area being tested.
- DEM_25 - Height data (DEM) data acquired in 1997 from the stereo-measurements of analogue photos of 25 m resolution.

The projection and datum details of the above listed data are UTM zone 31N ellipsoid WGS84.

[3] Previously a course 1km GTOPO30 DEM of the world was used as specified in the 'RapidEye Standard Image Product Specifications', January 2009.

[4] Points created using automatic image matching with the ADS40 (Leica Geosystems) digital airborne orthoimage of 0.50m pixel size.

[5] 25 m resolution DEM data acquired in 1997 from the stereo-measurements of analogue aerial photos.

[6] Circular error at 90% confidence (CE90) describes horizontal accuracy, while linear error at 90% confidence (LE90) describes vertical accuracy. 4.292m CE90 roughly corresponds to 1-D RMSE of 2.2m.

Methodology

The EU standard for the orthoimagery to be used for the purpose of the Common Agriculture Policy (CAP) Control with Remote Sensing (CwRS) requires the assessment of the final orthoimage ('Guidelines for best Practice and Quality Checking of Ortho Imagery'. Issue 3.0. by Dimitrios Kapnias, Pavel Milenov and Simon Kay, EUR 23638 EN – 2008). The RMS error calculated for Independent Control Points (points not included in the sensor model parameter estimation process) in each dimension (either Easting or Northing) is used to describe the required product accuracy.

According to the Common Technical Specifications for the 2009 Campaign of Remote-Sensing Control of Area-Based Subsidies (ITT no. 2008/S 228-302473, FMP no.10021), in the case of the RapidEye orthoimage the RMS error calculated for Independent Control Points (ICPs) in each dimension should not exceed 11m.

Product 3A

In order to evaluate the geometric characteristics of the 3A RapidEye image product, it is enough to perform the external quality control that is to check its accuracy on the set of points that were not used during the model parameter estimation (also referred to as independent control points).

The two sets of GCPs were independently used during this analysis in order to evaluate if their accuracy differences significantly change the final product accuracy (described as 1-D RMSE). The external quality control results allowed also analysing the relationship between the RapidEye image across track incidence angle and the image geometric quality.

As mentioned before, also slightly modified RapidEye Product 3A was also produced in order to study the influence of the auxiliary data used for the ortho-production on the final product accuracy. We analysed the following additional image products:

- 3A tiles created using the GCPs_ADS40 and DEM_25 (both auxiliary data were provided by the CID Action).
- the exact same tiles as above, but created with the GCPs_ADS40 and the standard RapidEye SRTM DEM.

For both these products 12 ground control points were used for orthoimage generation.

Product 2A

With regards to the 2A RapidEye image product, it is provided as geo-tiff files and can be ingested by the professional remote sensing software systems (e.g. PCI, ERDAS, ENVI, Socet Set, etc.). According to the RapidEye product specification, the 2A product is a geo-referenced and resampled image. The products the CID JRC was provided with are close to nadir (the greatest across incidence angle does not exceed 10 deg), the AOI (area of interest) is relatively small (tiles of 25kmx25km), so are the height differences of the Maussane test site (over which the images were taken). Taking all these aspects into account, the author followed the advise of the leading member of the RapidEye Calibration and Validation Group, and performed the simple polynomial transformation (warping) followed by the resampling to achieve the ortho product and be able to perform the external quality control (similarly to the product 3A evaluation).

Mathematical Model

The following mathematical models were introduced to model the tested RE imagery products:

- model introducing SHIFT by subtracting the average residual;
- model introducing the linear polynomial transformations of the 1-st order (also referred as to polynomial warping).

Analytical subtracting of the average residual (from each of the residuals, separately for X and Y coordinate), can be also done by introducing the zero-order linear polynomial.

The distribution and number of the GCPs is very important, especially in case of using the first-order (or more) adjustment. In the presented analysis, the set of 6 well distributed over the whole area of interest (AOI), ground control points were used for modeling.

F-Snedecor Test

In the presented study, the product quality analysis is followed by the mathematical model appropriateness evaluation based on the F-Snedecor test. The F-Snedecor significance test evaluates the deviation between the variances of the mathematical models (raw 2A product, model that introduces shift, and first order polynomial warping), and checks if the differences (deviations) between variances are statistically significant.

Analysis of the Results

Product 3A Quality Analysis

In order to evaluate the geometric characteristics of the 3A RapidEye image product, the 1-D RMS error was calculated using the residuals between the ground control points coordinates (GCPs_DGPS data set) and their coordinates measured on the RapidEye 3A product.

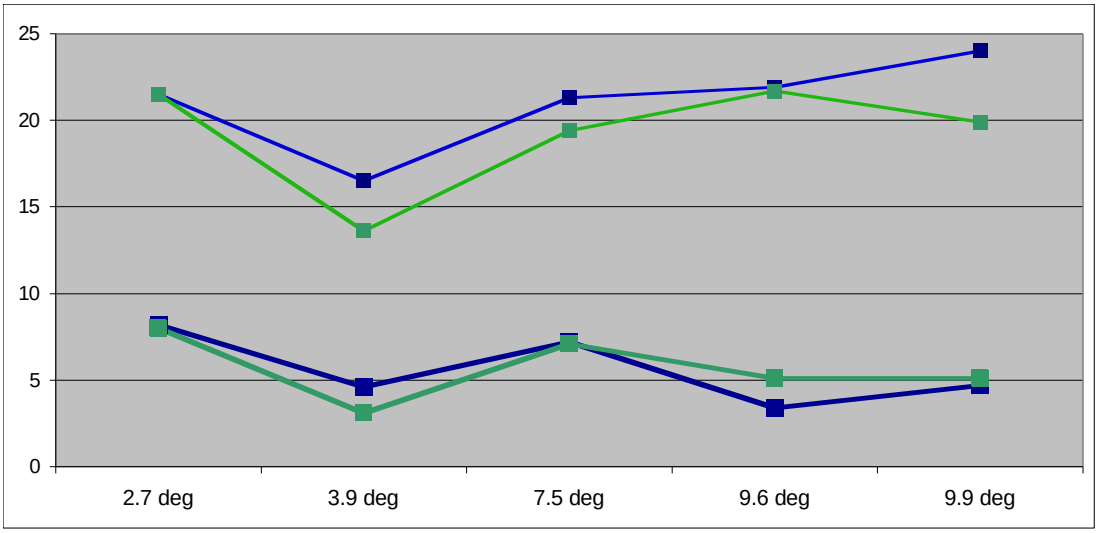
Please, not that the following analysis the RMSE based on the measurements of the ICPs on the final orthoimages are presented, and they are described in meters.

The average 1-D RMSE for the standard 3A RapidEye image product is 21.0m and 19.2m, respectively for X and Y direction. The results of quality analysis are summarized in the following table.

Across Track Incidence Angle	**RMSE_ICP_X (EQC)**	**RMSE_ICP_Y (EQC)**	**RMSE_ICP_X (NO shift)**	**RMSE_ICP_Y (NO shift)**
2.7 deg	21,5	21,5	8,2	8
3.9 deg	16,5	13,6	4,6	3,1
7.5 deg	21,3	19,4	7,2	7,1
9.6 deg	21,9	21,7	3,4	5,1
9.9 deg	24,0	19,9	4,7	5,1
Average	**21,0**	**19,2**	**5,6**	**5,7**

The accuracy equal to 4 pixels is astonishingly small for the new generation HR satellite imagery, therefore, in the next step the SHIFT was eliminated by subtracting the average residual. The average RMSE in X and Y direction after introducing model with shift, are close to one pixel (5.6m and 5.7m, respectively). Such results are quite satisfactory, however, their variations are plus/minus half pixel.

The following graph illustrates the relationship between the across incidence angle and the standard 3A ortho-product accuracy (X direction in blue, and Y direction in green). One can notice that the RMSE remain almost unchanged with increasing across track incidence angle.



The next table summarizes the quality study of the 3A RapidEye product based on more accurate ground and/or height data.

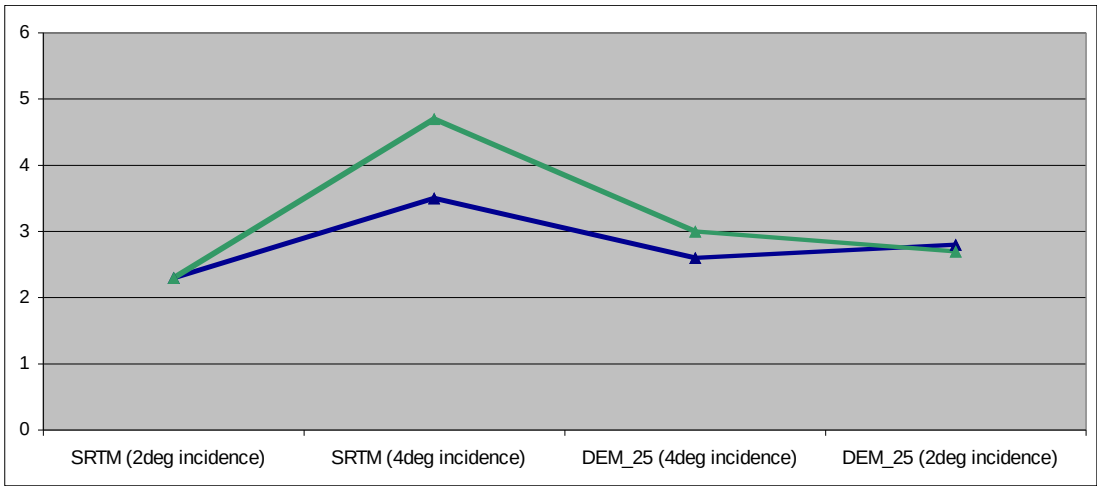
Firstly, only the better height data was used for the 3A RE production, however, the accuracy of the final ortho product did not improve (see the table below).

Across Track Incidence Angle + DEM_25	RMSE_ICP_X (EQC)	RMSE_ICP_Y (EQC)	RMSE_ICP_X (NO shift)	RMSE_ICP_Y (NO shift)
3.9 deg	20	15,2	9,9	7,4
4.1 deg	26	13,1	4,9	4,9

Then, the more accurate GCPs (GCPs_ADS40) were included into 3A RapidEye ortho-production.

GCPs_ADS40	DEM_25 or SRTM-3	RMSE_ICP_X	RMSE_ICP_Y
Yes	SRTM	2,3	2,3
Yes	SRTM	3,5	4,7
Yes	DEM_25	2,6	3
Yes	DEM_25	2,8	2,7
Average		**2,8**	**3,2**

The graph bellow summarizes the relationship between the accuracy of the final ortho-product and the accuracy and resolution of the auxiliary data used for the ortho-production. One can notice the 1-D RMSE (X direction in blue, Y direction in green) remain almost unchanged with increasing across track incidence angle. The same conclusion can be drawn as regards the resolution of the DEM data used for ortho-production.



The most important conclusion is that the accuracy of the 3A RapidEye Ortho Product is influenced by the accuracy of the GCPs used during ortho-production. Based on the available image test data, one can notice the 50% accuracy improvement, however, it must be underlined there that the number of the ground control points was also doubled (12 points from GCPs_ADS40 were used for each tile orthorectification instead of usual 5).

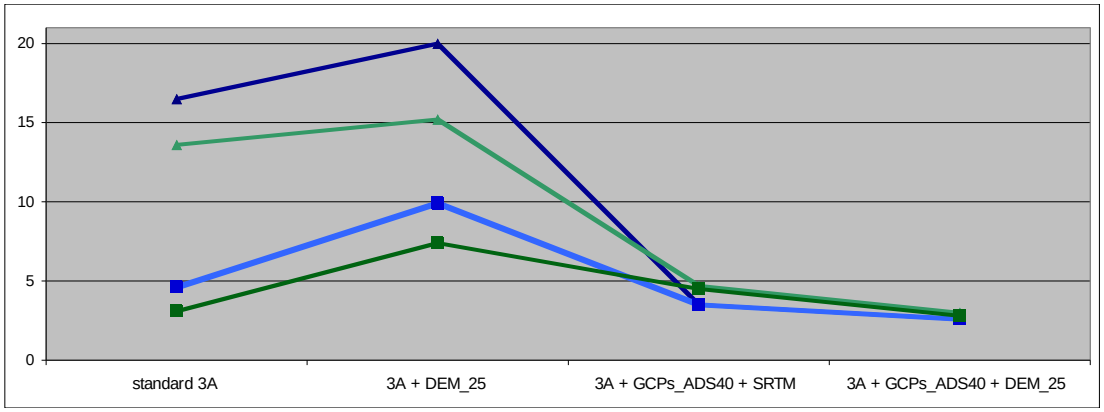
The following table and the graph summarize the quality results of the 3A ortho product based on the same input RapidEye image (chacterised by 3.9 deg across track incidence angle). The 1-D RMSE was calculated for the standard 3A product (GCPs form Global Landsat + SRTM), the product based on improved DEM (DEM_25), the product with improved GCPs (GCPs form ADS40 + SRTM), the product based on the improved GCPs and DEM data (GCPs form ADS40 + DEM_25).

The introduction of the zero-order polynomial (shift-only) for the cases where GCPs of better accuracy are used for ortho-creation is unnecessary (these results are included in the table for the visualization purposes).

Across Track Incidence Angle	RMSE_ICP_X (EQC)	RMSE_ICP_Y (EQC)	RMSE_ICP_X (NO shift)	RMSE_ICP_Y (NO shift)
standard 3A	16,5	13,6	4,6	3,1
3A + DEM_25	20	15,2	9,9	7,4

3A + GCPs_ADS40 + SRTM	3,5	4,7	3,5	4,5
3A + GCPs_ADS40 + DEM_25	2,6	3	2,6	2,8
Average			**5,1**	**4,5**

The obvious remark is that the ortho-product accuracy improved with better GCPs (GCPs from ADS40). Again it should be underlined that not only GCPs accuracy improved but their number is doubled (per scene).

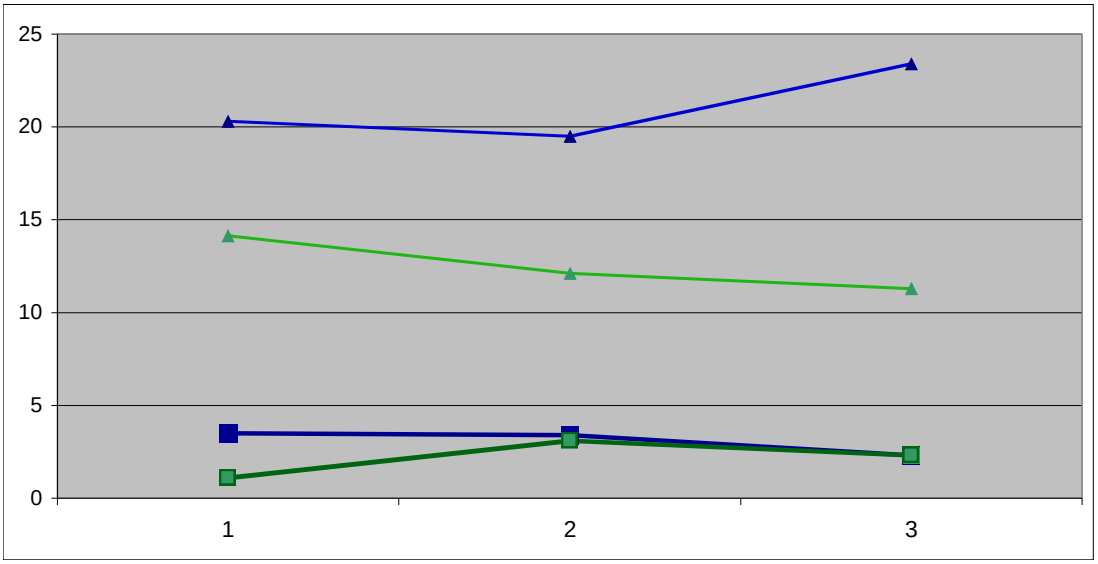


Please, note, that by the simple elimination of the systematic error (shift), the accuracy of the standard 3A product is comparable to the accuracy of the ortho-product that was produced based on higher number, and more accurate ground control points.

Product 2A Quality Analysis

With regards to the 2A RapidEye image product, its quality was evaluated based on similar methodology that was used for the 3A product, because there is not much difference between these standard image products: they are both geo-referenced and resampled. Level 2A data is also delivered as 16bit geo-tiff files, and can be ingested by all professional remote sensing software systems (e.g. PCI, ERDAS, ENVI etc.).

The coordinates of the points that were not used for 2A geo-referencing, were measured on the product. Then the RMS error was calculated. The quality results are indeed similar to these of the product 3A. The next step was the elimination of the systematic errors (shift). Again the quality increased to less then one pixel.



Then the simple polynomial warping of the first order was performed using the ERDAS IMAGINE remote sensing software. During the image warping the RMSE in both direction was calculated (see table below).

Product name	RMSE_X	RMSE_Y	RMSE_X (NO shift)	RMSE_Y (NO shift)	RMSE_X (1st order warping)	RMSE_Y (1st order warping)
2A_NAC_766285_36713	20,3	14,13	3,5	1,1	2,2	0,7
2A-NAC_766288_36713	19,5	12,1	3,4	3,1	1,5	1,7
2A-NAC_766284_36713	23,4	11,3	2,3	2,3	0,8	0,9
Average	**21,1**	**12,5**	**3,1**	**2,2**	**1,5**	**1,1**

After the polynomial warping, the 2A product was again a subject to resampling, and then the external quality control, however, this time the accuracy decreased, to 3-4meters (1-D RMSE) on average.

Therefore the question is not only what accuracy we can achieve but whether the improvements of the RMSE are statistically significant.

Mathematical Model Appropriateness

With regards to the 2A RapidEye image product, the product quality analysis is followed by the mathematical model appropriateness evaluation based on the F-Snedecor test. The F-Snedecor significance test evaluates the deviation between the variances of the mathematical models and checks if the differences (deviations) between variances are statistically significant. In this study the three mathematical models were used, namely: raw 2A product, model that introduces shift, and model that introduces first order polynomial warping.

The following naming convention is used in this report: Fcrit (α ,N, N-K) describes the critical values of the F-Snedecor statistics determined for N and N - K degrees of freedom at the chosen significance level α=0.05 (where N – number of the points, K number of the parameters to be determined within the model). In the presented quality analysis the significance level α=0.05 was used.

PRODUCT 2A 2009-03-15t111917_re4_2a-nac_766285_36713.tif

Testing the deviations between the variations for the firs two models (that is raw 2A standard product, and the zero-order polynomial (shift elimination), we can read from the 'Statistical Tables' the Fcrit(0.05,6,5)= 4,950. Our deviations between variations are 33 and 159 respectively for X and Y direction. Therefore the deviations are statistically significant, and model that introduces shift is suitable!

Secondly, we use the F-Snedecor significance test to evaluate the deviations between variations of the mathematical model that models shift, and the first level polynomial warping. In that case, the Fcrit(0.05,5,3)= 9,014, while our deviations between variations are 1.4 and 1.6 (respectively for X and Y direction). According to F-Snedecor test the deviations are not statistically significant, and it is enough to use zero order polynomial (shift elimination).

The F-Snedecor significance test was also used in the following 2A products analysis:

PRODUCT 2A 2009-03-15T111917_RE4_2A-NAC_766288_36713.tif

Fcrit(0.05,6,5)= 4,950 , while our deviations between variations are 32 and 16 (respectively for X and Y), therefore the deviations are statistically significant, and model that introduces shift is suitable.

Fcrit(0.05,5,3)= 9,014 , while our deviations between variations (X) 5.2 and (Y) 3.4, therefore the deviations are not statistically significant, and it is enough to use zero order polynomial warping.

PRODUCT 2A 2009-03-16T112018_RE5_2A-NAC_766284_36713.tif

Again the values of 102 (X) and 25 (Y) exceed the critical value Fcrit(0.05,6,5)= 4,950, while our deviations between variations of shift modelling, and first order polynomial warping – not, therefore the model that introduces shift is suitable as much as necessary.

The similarities between the 2A and 3A products allow the author to treat the results from the above-mentioned appropriateness test as equally valid for both products, however for the following two RE 3A products the F-snedecor test shows as follows:

PRODUCT 3A 2009-02-15\ 2009-02-15T111140_RE5_3A-NAC_665288_35179.tif

The variations values 42 and 18 (respectively for X and Y directions) exceed the critical value Fcrit(0.05,6,5), while the deviations between variations of shift modelling and the first order polynomial warping – not, therefore the model that introduces shift is suitable enough.

PRODUCT 3A 2009-03-15\ 2009-03-15T111917_RE4_3A-NAC_678276_35250.tif

The variations values 92 and 57 (respectively for X and Y directions) exceed the critical value Fcrit(0.05,6,5), while the deviations between variations of shift modelling and the first order polynomial warping (being 2.2 and 3.3) – not, therefore the model that introduces shift is suitable enough.

The following table summarises the quality analysis done on three 2A and two 3A RE standard imagery products. Note that for all these product the same GCPs/ICPs were used.

Product name	**RMSE_X**	**RMSE_Y**	**RMSE_X (NO shift)**	**RMSE_Y (NO shift)**	**RMSE_X (1st order warping)**	**RMSE_Y (1st order warping)**
2A_NAC_766285_36713	20,3	14,13	3,5	1,1	2,2	0,7
2A-NAC_766288_36713	19,5	12,1	3,4	3,1	1,5	1,7
2A-NAC_766284_36713	23,4	11,3	2,3	2,3	0,8	0,9
Average 2A	**21,1**	**12,5**	**3,1**	**2,2**	**1,5**	**1,1**
3A-NAC_665288_35179	22,7	19,0	3,6	2,8	2,2	0,5
3A-NAC_678276_35250	20,0	13,9	2,1	1,8	1,4	1,0
Average 3A	**21,3**	**16,4**	**2,8**	**2,3**	**1,8**	**0.7**

Summary of Key Issues

This analysis aimed at describing the geometric image quality of the RapidEye standard imagery in the context of its potential use for the purpose of the Common Agriculture Policy (CAP) Control with Remote Sensing (CwRS). Such evaluation requires the assessment of the final orthoimage.

The preliminary quality analysis of the 2A and 3A RapidEye image products confirms the well-known rule that more accurate auxiliary data used for othoimagery generation improves the final product. However, it implies the availability of such data (GCPs, DEM), and its provision to the RapidEye company in a timely manner (not mentioning data use and licensing policy issues).

In order to avoid unnecessary inconvenience, the standard 2A or 3A RapidEye image products can be used, however, it is necessary to eliminate the shift by introducing a polynomial transformation using zero-order adjustment (shift-only/bias-only). This action can be performed by means of any off-the-shelf remote sensing or photogrammetric system using the generic polynomial sensor model[7] or, simply, any maths program (e.g. excel) by subtracting the average residual.

The polynomial transformation requires the set of the ground control points. It is advisable to use a set of well-defined points that are easily identifiable on the ground, on the independent source of higher accuracy, and on the product itself[8]. In case of the RapidEye 2A and 3A imagery products, there is no benefit if GCPs with less than 2 meters RMSE (root mean square error) are used.

The distribution and number of the GCPs is very important, especially in case of using more than zero-order adjustment. In the case of using 2A and 3A RapidEye standard image products for CAP CwRS purposes, it is recommended to use at least 6 ground control points (GCPs), well distributed over the whole area of interest (AOI).

Based on the limited RapidEye sample images, the RapidEye Orthoimagery Requirement (1-D RMSE of < 11m)[9] is fulfilled for both 2A and 3A products, provided the shift elimination based on the set of minimum 6 well-distributed ground control points.

JRC IPSC/G03/C/JN/ D(2009)(10879)

Int. ref: file://S:\FMPArchive\C\10879.pdf

[7] Note that for both the ERDAS IMAGINE and the Geomatics OrthoEngine, the smallest polynomial order is the first one, however.

[8] 'Guidelines for Best Practice and Quality Checking of Ortho Imagery' Issue 3.0. by Dimitrios Kapnias, Pavel Milenov and Simon Kay, EUR 23638 EN – 2008.

[9] According to the Common Technical Specifications for the 2009 Campaign of Remote-Sensing Control of Area-Based Subsidies (ITT no. 2008/S 228-302473, FMP no.10021).

European Union

EUR 24129 EN – Joint Research Centre – Institute for the Protection and Security of the Citizen
Title: RapidEye – Initial findings of Geometric Image Quality Analysis
Author(s): Joanna Krystyna Nowak Da Costa
Luxembourg: Office for Official Publications of the European Union
2009 pp. – 210 x 297 mm
EUR – Scientific and Technical Research series – ISSN 1018-5593
ISBN 978-92-79-14624-4
doi:10.2788/52504

Abstract
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LB-NA-24129-EN-C

ISBN 978-92-79-14624-4

9 789279 146244

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