ORTHORECTIFICATION AND GEOMETRIC QUALITY ASSESSMENT OF VERY HIGH SPATIAL RESOLUTION SATELLITE IMAGERY FOR COMMON AGRICULTURAL POLICY PURPOSES

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KEY WORDS: IKONOS, QuickBird, EROS, geometry, errors, quality, agriculture

ABSTRACT:

37 sites for the checking of farmers' aid applications under the Common Agricultural Policy (CAP), covering an area of over 10,000 km^2, were imaged with very high resolution (VHR) images (Ikonos, QuickBird, Eros) in the framework of an operational testing programme. Determining the performance of VHR imagery orthorectification, and geometric quality assessment of the results in relation to the different factors, were important goals of the programme.

The study, located throughout the extended European Union (15 Member States and 10 accession countries) and managed by the European Commission in parallel to its operational work, was intended as a broad validation programme of VHR data use. Two sources of results and experiences – one delivered by contractors and a second one from internal reprocessing of orthorectification done at the JRC – were compared and evaluated.

This paper presents results recorded for Ikonos (Geo Ortho-kit), QuickBird (Standard OrthoReady) and EROS 1A level data, applying different approaches (variants, models) to orthorectification. The results show that VHR orthoimage products generally meet the geometric specification of 2.5m (1D) RMSE corresponding to EU technical requirements. Existing limits of geometric accuracy under certain circumstances are identified and described. Quantitative and qualitative evaluations of orthorectified imagery were carried out using independent check points, according to a standardized protocol, helping to identify the influence of different factors on the geometric accuracy level of orthoimage products. A positive outcome of this assessment is a demonstration of the validity of the use of VHR remote sensing inside the CAP for control purposes, as well as for the use of spaceborne VHR in CAP applications in general.

1. INTRODUCTION

Very high resolution satellite image technology provides a rich source of up-to-date, large scale, geospatial Earth-observation data. Such images have already confirmed their usability in many mapping oriented application areas. The parameters (image resolution, repeat cycle, etc.) of VHR sensors combined with metric image properties have strong potential for Control with Remote Sensing (CwRS), one of methods for verification of EU Common Agricultural Policy (CAP) aid applications by farms in Europe. Such images can be used for determination of the area and land use of declared agricultural parcels. To be applicable for this purpose the images have to meet first certain requirements defined in relevant guidelines stipulated by European Commission (EC, 2004). One of the important criteria is the orthoimage geometric accuracy at least 2.5m as $RMSE_{1D}$ measured on a set of independent check points.

Taking into account the fine spatial resolution of panchromatic VHR satellite images and their information content, it can be noted that the planimetric accuracy of the delivered raw image, in comparison to ground sampling distance (GSD) (or pixel size) is relatively poor, due to a number of geometric distortions. The inherent geometric accuracy of images and their approximate georeferencing (computed for some product levels from the source satellite orbital position and imaging geometry) needs to be improved for CAP applications by applying 3D geometric rectification (orthorectification), to be able to achieve the 2.5m RMSE accuracy. Orthorectification is a process which converts images into map-like (metric quality) form by accurately removing from it satellite, scanner (camera), and terrain related distortions. The resulting orthoimage can then be directly applied in GIS or mapping oriented area applications e.g. terrain analysis, thematic information extraction, area measurements, etc.

The theoretical basis for orthorectification methods of VHR satellite imagery, as well as some research based results, are well documented in the literature although the VHR technology is still relatively new (e.g. Grodecki, 2002, Toutin et al., 2002, Jacobsen, 2002). Consequently, the main geometric accuracy constraints for orthorectified products and approximately which conditions (especially for ancillary data such as ground control) are required to achieve a certain level of accuracy are well known. Nevertheless, it is often more difficult to meet all the requirements in operational production conditions, unlike research or scientifically oriented study conditions. In a large scale operational mode, therefore, practical questions can arise concerning the availability of good quality ancillary data, cost effective procedures and methods in given circumstances, and how far the departure from the best practice type and quality of input data can still give acceptable results. These issues are important for the preparation of correct technical recommendations, as well as with respect to the success of a given project or campaign.

The goal of this validation programme is directly linked to VHR orthoimagery use in the CAP, and recommendations to a large community of user. The paper is focused on geometric accuracy issues of image orthorectification, and describes the results obtained from the programme in this respect. A positive result of the assessment for images acquired throughout different geographical sites in the Europe can confirm the validity of the use of VHR satellite images for control purposes and other applications related to the CAP.

2. OVERVIEW OF THE VHR SATELLITE IMAGE DATA AND GEOMETRIC PROCESSING

2.1 Basic characteristics of the sensors

Table 1 gives an overview of operationally active VHR satellite systems used in the JRC 2003 campaign.

Features / sensors	Ikonos	QuickBird	EROS A
Launch Date	24 Sept.1999	18 Oct.2001	5 Dec.2000
Satellite Altitude	681 km	450 km	480 km
Resolution [m] (GSD - in nadir)	0.82 pan 3.28 ms	0.61 pan 2.44 ms	1.8 pan
Image Swath (in nadir)	11.3 km	16.5 km	13.5 km
Revisit Time ~ (40° lat., 15° off-nadir)	6 days	8 days	7 days
Dynamic Range	11-bits /pixel	11-bits /pixel	11-bits /pixel

Table 1. Basic technical parameters of VHR satellites in 2003.

2.2 Distortions in image geometry

An image is a collection of single lines registered continuously by pushbroom line scanner. In the direction of the linear array, a perspective projection can be defined and along the perpendicular (to linear array) direction a parallel projection is present. The exterior orientation for each line in the image is different, but with regard to the level of regularity and stability of satellite orbit, the change can be considered as a function of time. The following geometric distortions are related to the image formation process (Toutin et al, 2002):

- distortions caused by the platform and mainly related to the variation of the elliptic movement around the Earth (position, velocity, and attitude),
- distortions due to the imaging sensor (the calibration parameters, such as the focal length and the instantaneous field of view; the panoramic distortion in combination with the oblique viewing system, the Earth curvature and the topographic relief changes the ground pixel sampling along the column);
- distortions due to the Earth (the rotation generates lateral displacements in the column direction between image lines depending of the latitude; the curvature creates variation in the image pixel spacing; the topographic relief generates parallax in the scanning azimuth)

In addition to the above mentioned distortions, deformations arise during the georeferencing process, i.e. the approximation of the geoid by reference ellipsoid and the projection of reference ellipsoid on the tangent plane.

Most of distortions (with the help of system related data) is corrected at the ground receiving station, but others are the subject of further processing, often done by the end user. More detailed considerations about VHR image distortions and correction methods as well are included for example in: Toutin 2003, Toutin et al, 2002, Grodecki & Dial 2001,

2.3 Imagery product levels for orthorectification

Different product levels for a given satellite system are available on the market. The type of product is defined by radiometric and geometric pre-processing levels, with some influence on pricing. Some products (not tested here) are already orthorectified with high accuracy but they have a corresponding higher price, as well as usually a requirement to supply ancillary data to the image provider. It is generally considered that the most appropriate processing levels for creating accurate 3D geometric correction are:

Ikonos Geo orthokit: geometrically corrected and rectified to a specified ellipsoid and map projection, supplied with Image Geometry Model (camera information, RPC), enabling the complete and accurate sensor geometry at the time of the image collection. The pre-processing removes image distortions introduced by the collection geometry and re-samples the imagery to a uniform ground sample distance and specified map projection. GEO has 15 m (CE 90%) standard horizontal accuracy, excluding effect of terrain displacement, (SI, 2004).

QuickBird ortho ready standard: radiometrically corrected, sensor corrected, geometrically corrected, and mapped to a cartographic projection. No topographic corrections applied. Provided with RPCoefficients enabling orthocorrection. Standard Imagery products have a positional accuracy of 23- meter (CE 90%), excluding any topographic displacement (Eurimage, 2004). Ground reference is based on refined satellite attitude and ephemeris information without requiring the use of GCPs.

EROS 1A: radiometric system correction - calibrated and gain adjusted to correct for known radiance response characteristics of the camera sensor system, no geometric system correction. No RPC data is available from the image provider.

2.4 3D geometric correction methods

The geometric correction process for VHR satellite images, unlike high resolution images, is somewhat sensitive and needs more accurate ancillary data. This is due to the sensor (image) parameters, acquisition conditions, and potentially achievable target planimetric accuracy. The 2D polynomial based approach – often sufficient for geometric correction of high resolution images – is no longer useable for VHR images if the commensurate accuracy of final product is intended; the significant (in relation to image GSD) level of distortion – especially relief displacement – demands 3D geometric correction (orthorectification) methods. Such methods can be divided basically into two categories:

- **parametric**: rigorous (physical, deterministic) sensor modelling with mathematical modelling of viewing geometry physical components (platform, imaging sensor, earth, map). Such models are complicated due to the information released (or not) by image suppliers, although approaches exist to overcome this problem e.g.: Toutin's model for VHR satellite images, available in PCI Geomatica software.
- **non-parametric**: the Rational Functions mathematical model (RF), that builds a correlation between the pixels and their ground locations (continuous mapping between image and object space) based on ratio (separately for row & column) of two cubic polynomial functions. Polynomial coefficients (the rational polynomial coefficients - RPC) are derived using physical sensor/camera model (at the ground station) and are distributed by image vendor with certain processing level products.

The chosen approach to orthorectification depends frequently on available ancillary data, and the possibilities of the software accessible to the user. Both constraints have implications on the choice of image type and its processing level. The following options concerning the geometric model for image correction can be considered in practise (Table 2):

Model	GCPs	Remarks
Rigorous (physical) satellite model	Usually 8 for all three sensors	IGM/RPC file is ignored but information from metadata file are required
Rational Functions (RPC) calculated from user GCPs	Many GCP's required, usually >20	Effectively repeats work done by image provider
Image geometry model (IGM / RPC delivered with image)	No additional GCP's	Limited geometric accuracy
Refined image geometry model (IGM / RPC delivered with image)	2 to 4 GCPs per image	

Table 2. 3D geometric models and GCPs requirements.

The first and last options make up a reasonable and cost effective choice where high accuracy of final product is intended.

Several published papers (Kay et al., 2003, Cheng et al, 2001) confirm quite good results using RPCs refined by a few GCPs. This refinement adjusts the RPC increasing geopositional accuracy of the image, improving co-registration between the image and DEM, thus ensuring more accurate 3D geometric rectification.

Of course, the GCPs (and also check points) need to be carefully selected and identified in the image before their accurate surveying in the field. Attention should also be drawn (during the ground point selection) to the fact that in orthorectification distortions due to topography and varying Earth surface heights are removed; however, man-made features standing on the terrain surface like buildings, bridges or channels will have significant displacement not modelled in the DEM, and thus cannot be used reliably for GCPs.

3. THE VHR VALIDATION PROGRAMME

3.1 The aims of the programme

With regard to information content and potentially achievable positional accuracy, VHR satellite images are considered to be extremely useful for CwRS and Land Parcel Identification System (LPIS) applications in the CAP. In this context, the images (after orthorectification) are utilized to determine the area and land use of declared agricultural parcels. The importance of VHR satellite images, their potential usefulness and advantages are also considered from the perspective of CAP reform process and its control, monitoring, and management requirements.

The study managed by the European Commission in parallel to its operational work related to CwRS campaign, was intended as a broad validation programme of VHR data use with the main goals described as follows:

- establishing the realistic geometric target specification for the different data types concerned, initially assumed to be 2.5m $RMSE_{1D}$ (EC, 2003)
- determining the performance of orthocorrection systems in relation to the different site conditions experienced (ancillary data quality),
- confirming the potential of existing platforms to deliver reliable and timely data to:
  - a) the CwRS programme,
  - b) other CAP applications (IACS) in general.

The detailed technical tasks include identification of factors influencing the geometric quality of the final orthoimage product, as well as testing different approaches and models used for the orthorectification.

The VHR images were orthorectified by the respective contractors responsible for each site in the operational context of the 2003 CwRS campaign purpose. A brief protocol with recommendations for ancillary data quality was circulated, and technical assistance offered on an *ad hoc* basis. The raw and orthorectified images, together with ancillary data, were delivered to JRC, where additional orthorectification tests and a final evaluation were done.

3.2 The study area and data

The sites, located in a wide range of geographical conditions in different European countries (Fig. 1), represent a quite diverse set with respect to:

- terrain (relief) characteristics,
- operational, production conditions,
- ancillary data source and quality.

12 sites were covered by Ikonos images (Geo Ortho kit) with view angles up to 20.15º, 17 sites by QuickBird (Standard Orthoready) with view angles up to 14.2º, and 3 sites by EROS images (Level 1A) with view angles up to 20.18º. The majority of sites were covered by single scene images, but some sites were covered by 2 or more overlapping images.

The ground control points and independent check points were acquired in some countries through GPS-survey (accuracy of 1m or better), while for others the points were obtained from orthophotomaps (scale 1:5000) or digital vector maps (with reference scale 1:2500). DEM cell sizes also varied, i.e. between 5m and 50m, although according to reported metadata all were equivalent to a $RMSE_Z$ of <5m, this being the recommended maximum uncertainty. Although the number of GCPs required was defined by recommendations, the number delivered for some sites was fewer than expected, decreasing in such cases the flexibility and possibilities of additional variants of orthorectification planned to be done at JRC. In addition, due to some incompleteness of ancillary data, not all sites are included in the set of results described in this paper.

4. APPLIED METHODS AND PROCEDURES

4.1 Orthorectification of images

Raw and orthorectified images, delivered by contractors with ancillary data (DEM, GCPs, check points, metadata), were selected for further work done at JRC, which included:

- creation of meta information concerning all the images, ancillary data, sites, and also successively obtained results,
- orthorectification with different options (other than chosen by contractors),
- comparison and evaluation of two types of orthorectification results:
  - delivered by contractors,
  - done at the JRC (other variants).

Additional orthorectification done at JRC (cf. by contractors) assumed different, pseudo-randomly chosen options for processing, taking into account: number of GCPs, type of 3D rectification model, other software. Consequently, for sites with multiple images, more results were produced. The final set of results can be considered as diverse and quite representative, as well as useful for advanced factorial analysis.

In practise, one of two approaches to orthorectification was applied by contractors, i.e. space resection using either a rigorous model or the RPC-based model with refinement by a few (usually) GCPs. Both approaches were used also at JRC. As software, Erdas Imagine, PCI Geomatica, Socet Set orthorectification modules were used by contractors, and PCI Geomatica and Erdas Imagine for the work done at JRC.

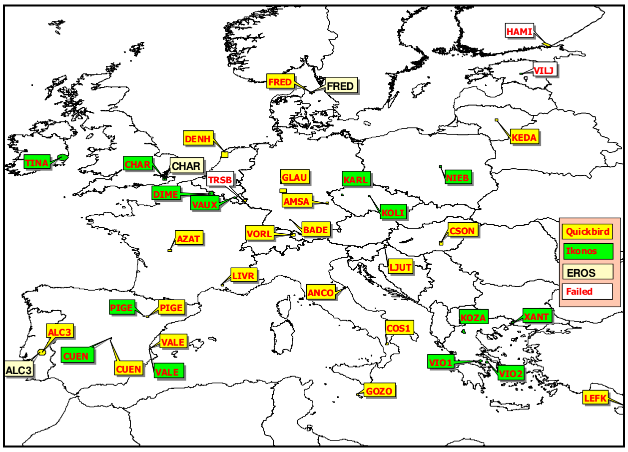

Figure 1: The VHR satellite imagery sites

4.2 Geometric quality assessment

In order to have both results (i.e. delivered by contractors and produced in JRC) comparable the uniform procedure for geometric evaluation of orthoimage products was applied:

- common guidelines, recommendations for all ortho producers,
- final accuracy check by one user in one software environment,
- independent check points (not GCPs) used, according to a standardized protocol.

The geometric accuracy of each orthorectified product was checked in a customised ArcView based application. Two types of output reports were generated from the application:

- a text report from checking procedure listing the check point X,Y discrepancies and final RMSE as 1D (i.e. separately for X and Y) and 2D (overall for XY),
- a diagram report form, which illustrates the vector discrepancies, useful in detailed considerations.

5. RESULTS AND ANALYSIS

5.1 Ikonos

The majority of Ikonos images were corrected within the specification of 2.5m $RMSE_{1D}$. The scatterplot of $RMSE_{X,Y}$ (Figure 2) shows that results based on GCPs taken from the maps are more heterogenous when compared with those based on GPS measurements. However, there is need for further evidence to conclude definitively the reason of such error value distribution. It can be noted from Figure 3 that the highest values of RMSE belong to the same site (Koza). For this site the control points were taken from orthophotomap (1:5,000) and DTM has resolution of 40m which might be not enough for some parts of terrain with more heterogeneous relief. A 1:5,000 scale orthophotomap was also source of GCPs for the 'Xant' site, where the DTM has resolution of 30m.

There is also significant difference between $RMSE_X$ or $_Y$ values for 'Koza' (not present for 'Xant') that may be caused by a probably poor DTM for this site, taking into account the scanning direction (west to east, which corresponds to $_Y$) for both sites.

For the rest of sites the RMSE values present acceptable levels, i.e. 2.5m and better, including those with image view angles up to 20.15º. Further analysis of the Figure 3, in which the sites are ordered according to increasing values of image view angle, shows that for this data set there are no clear relationships between the RMSE values and view angle change. There is also no clear evidence that RMSE values may be sensitive to number of GCPs or to the variation in the site elevation values (an approximate relief descriptor).

5.2 QuickBird

All the imagery checked met the 2.5m $RMSE_{1D}$ specification. The $RMSE_{X,Y}$ values presented on Figure 4 are very homogenous and quite low. This may however be due to the better quality (compared to many Ikonos sites) of ancillary data, supported through the analysis of Figure 5, in which the sites are ordered according to increasing values of image view angle. RMSE values generally seem to be not correlated with view angle change, or at least it is too weak to be detected by visual inspection. Some disproportion in value of RMSE for $_X$ and $_Y$ is visible for 'Lefk', 'Pige', and 'Cson' sites, but assuming the good quality of GCPs measured by GPS the reason can be rather related to DTM itself or its georeferencing.

For 'Keda' and 'Krui' (almost flat sites, no DTM), average heights were used for modelling; nevertheless the results are very good. It can also be noted that for these sites and image view angle range, neither the number of GCPs nor relief characteristics have a significant influence on the RMSE values.

5.3 EROS

Only three sites were covered by EROS images. All orthorectification was done with parametric modelling using different software. The GCPs were obtained as follows: for GPS surveyed 'Fred', for 'Char' from digital vector map (ref. scale 1:2500), and for 'Alc3' from orthophotomaps. For 'Fred' (almost flat) the corrected EROS basic scene results in RMSE values in an acceptable range (Table 3). For 'Alc3' and 'Char' sites, the so-called "vector scenes" (up to 32 km length) were acquired. The larger scene size, more heterogeneous relief, higher view angle together with some complexity of image (related to asynchronous acquisition mode) limits the possibility of achieving good geometric accuracy of orthorectified product.

Nevertheless, in part due to the image resolution (GSD = 1.8m) the results for 'Char' are quite good. For 'Alc3' the higher values of RMSE (comparing to 'Char') can be explained by the source of GCPs; for which only an orthophotomap with 2m pixel (resampled from 1m) was only accessible.

SITE	DEM gsd	No. of GCP	View. Angle	RMSE_X	RMSE_Y
FRED	50 (dH=10)	9	14,97	2,45	2,43
FRED	50 (dH=10)	9 *	14,97	2,71	2,13
FRED	50 (dH=10)	15 **	14,97	1,37	2,23
ALC3	50 (dH=134)	21	21,90	4,47	3,32
CHAR	50 (dH=180)	18	20,18	2,78	2,69
CHAR	50 (dH=180)	18 *	20,18	2,56	3,93

Table 3. RMSE $_{X,Y}$ for EROS: after DTM resolution, the dH values mean difference between extreme values of heights (relief) measured on GCPs and check points. Software used: * Socet Set, ** SipOrtho, PCI Geomatica in other cases.

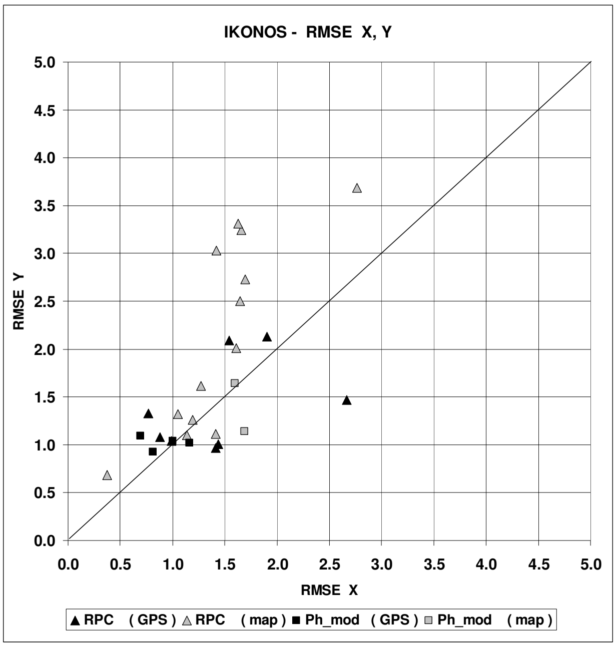

Figure 2: RMSE$_{X,Y}$ for Ikonos orthorectified images. Additional information concerns: model used (RPC or Physical (ph) model – parametric), source of GCPs (GPS or map/orthophoto).

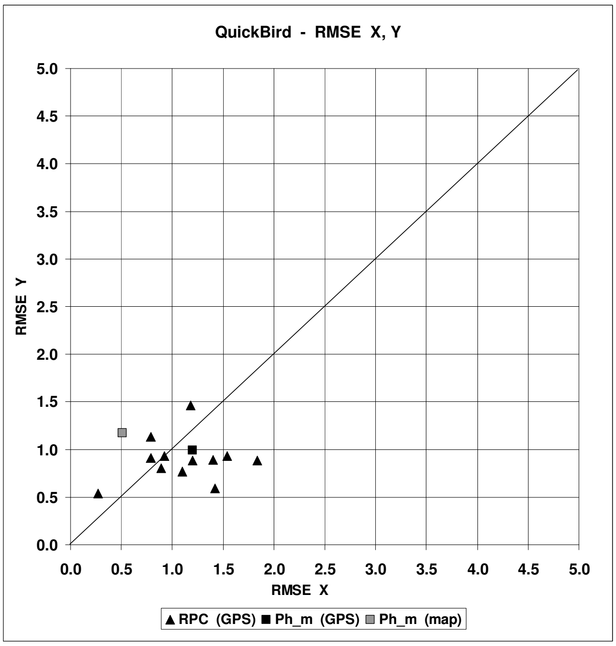

Figure 4. RMSE$_{X,Y}$ for QuickBird orthorectified images. Additional information concerns: applied model (RPC or Ph_mod – parametric), source of GCPs (GPS or map).

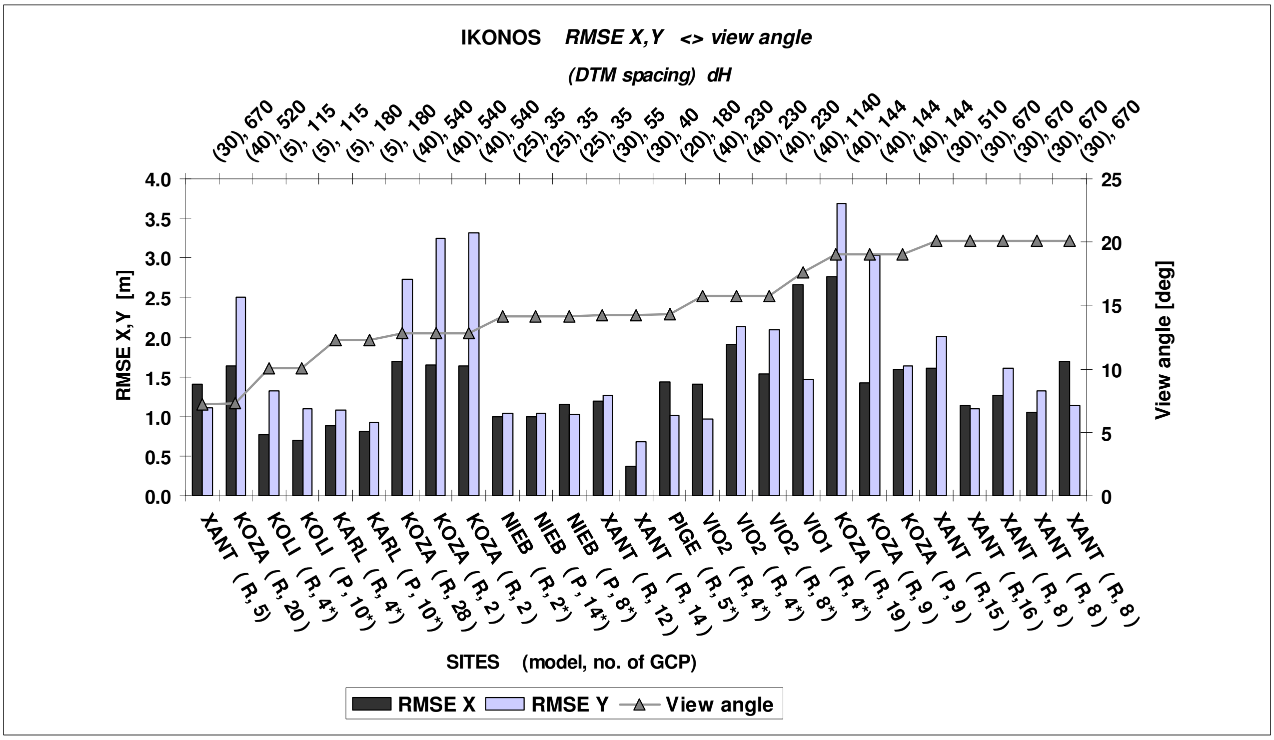

Figure 3. Ikonos RMSE$_{X,Y}$ versus image view angle, for different sites. The additional attached information concerns:
for 1st X axis: applied model (R – RPC, P – parametric), number of GCPs used for the orthorectification, * GPS measured GCPs,
for 2nd X axis: (DTM spacing), dH difference between extreme values of heights (relief) measured on GCPs and check points.

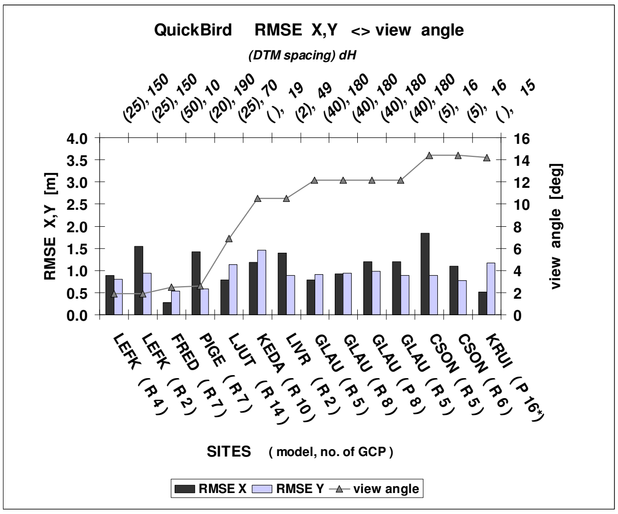

Figure 5. QuickBird $RMSE_{X,\ Y}$ versus image view angle, for different sites. The additional attached information concerns:

- for 1st X axis: applied model (R – RPC, P – parametric), number of GCPs used for the orthorectification, * GCPs from map,
- for 2nd X axis: (DTM spacing), dH difference between extreme values of heights (relief) measured on GCPs and check points.

6. CONCLUSIONS

For **Ikonos** and **QuickBird,** the results meet the geometric accuracy requirement of 2.5m $RMSE_{1D}$. There is no observed significant difference between the RPC and parametric model performance (PCI Geomatica and Socet Set based). Where ancillary data was of a good quality, any increase in number of GCP's above the recommended level made no difference to final accuracy. Based on the results obtained in the context of this trial, that in respect of using a limited number of GCPs, the RPC based approach may be considered as very reasonable and practical solution applicable for single-image orthorectification of VHR satellite images. For the images tested the view angle values up to 20.15º (Ikonos) gave acceptable results.

Further tests are needed to check to which extent extreme off-nadir angles can be used for successful orthorectification in this type of applications. Since higher off-nadir angles permit reduced revisit times, this is an important consideration.

The study confirmed the importance of the quality of ancillary data. The visible influence of quality of ancillary data (DEM, GCP's) on the accuracy caused also the partial masking of the other factors and made difficulties in clear identification of possible complex relationships.

For **EROS,** the results observed were at the limit of the specification in case of basic scene and flat areas. The vector scenes gave higher RMSE values, however, the ancillary data sets cannot be considered as optimal (low accuracy GCPs) making it is difficult to formulate reasonable conclusions for these cases. Nevertheless, the tests showed that for "vector scenes" at least the twice as many GCPs are needed for orthorectification process, compared to a basic scene.

The VHR validation program was a good opportunity to make a test and validation in more operational mode. It brought a wide range of different experiences and results and can be considered as important contribution to the process of implementation of VHR satellite images in CAP oriented broad area applications.

ACKNOWLEDGEMENTS

Due to the limited space available, we are only able to collectively thank all the contractors, image providers and administrations who took part in this testing program.

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