JRC Scientific and Technical Reports

THEOS Geometric Image Quality Testing – Initial Findings

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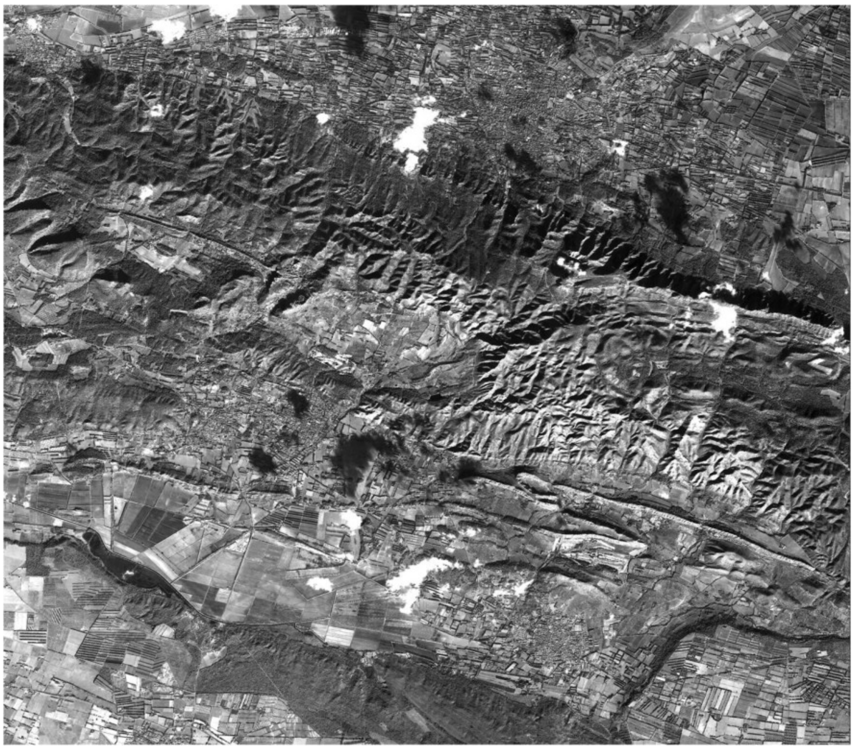

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1. Objective

This report summarizes the initial outcome of the geometric quality testing of the panchromatic, pan-sharpening and multispectral THEOS images acquired over the JRC Maussane Test Site for the Common Agriculture Policy (CAP) Control with Remote Sensing (CwRS) Programme.

2. Data description

2.1. THEOS satellite and image data

The THailand Earth Observation Satellite (THEOS) is the first operational earth observation satellite of Thailand, launched on October 1, 2008. It is equipped with two cameras: the one single band panchromatic camera and the multispectral one, both with the same spectral range between 450-900nm The sensor provides a high resolution panchromatic band of 2m resolution (22km of imaging swath) and four standard (blue, green, red, near infrared) multispectral bands of 15 meters resolution (90km swath). The Geo-Informatics and Space Technology Development Agency (GISTDA) owns and distributes the THEOS products (source: THEOS User Guide).

Apart from PAN and MS images THEOS provides also PAN-sharpened image which is created by the fusion of image information from the PAN high resolution and the MS colour image giving a high resolution MS image. It is generated by a dedicated algorithm adapted for THEOS (source: http://www.gisdevelopment.net/technology/rs/mwf09_THEOS.htm).

Orbital elements	
Orbit type	Sun Synchronous
Altitude	822 km
Inclination	98,7° (Sun synchronous)
Orbital per day	14 + 5/26 revolutions
Revisit frequency	2 days at 50° off-nadir 5 days at 50° off-nadir
Number of revolutions per day	14 + 5/26 revolutions
Orbit full cycle	26 days

Table 1A: THEOS parameters (THEOS User Guide, 2009)

Instruments	
Payload	B&W (PAN) and 4 MS (B, G, R, NIR)
Spectral band	PAN: 450nm - 900nm MS1 (Blue): 450nm - 520nm MS2 (Green): 530nm - 600nm MS3 (Red): 620nm - 690nm MS4 (NIR): 770nm - 900nm
Spatial resolution	2 m (PAN) and 15m (MS) at nadir
Number of pixels	12000 pixels (PAN); 6000 pixels (MS)
Radiometric resolution	8 bits/pixel
Swath (footprint)	22km x 22km (PAN), 90km x 90km (PS)
Viewing angle	±50° (roll/pitch tilt)

Table 1B: THEOS parameters (THEOS User Guide, 2009)

2.2. Processing Level Definitions of THEOS image data product

THEOS products are provided following levels:

Level 1A images are radiometrically corrected by performing detectors relative response equalization and radiometric abnormality removal. This product is intended for users who will perform their own geometric correction processing. Level 1A products are geo - referenced meaning that product annotations provide information about the image localization (THEOS User Guide, 2009).

Physical Characteristic		Processing Specifications	
Minimum orderable area	**1 scene**	Localization accuracy	**Better than 300m RMS**
Product Framing	**Scene-based**	Radiometric corrections	**Gain/offset coefficients; radiometric calibration, missing lines**
Final Product physical structure	**Scenes (no fractional scene)**		
PAN strip width	**12000 pixels**		
PAN scene size (approximate at nadir)	**22kmx22km**		
MS strip width	**6000 pixels**		
MS scene size (approximate at nadir)	**90kmx90km**		
Product Parameter		Delivery parameters	
Product Options	**PAN, MS**	Output products delivery media options	**FTP, CD, DVD**
Number of bits/pixel in delivered product	**8 bits**	Image data format options	**GeoTIFF**

Digital scanning method	**Linear with a maximum value set to 255**	Image compression options	**High/low**
Resampling options	**Bi cubic**		
Output pixel spacing	**2m (PAN) 15m (MS)**		
Cloud cover	**0-20%**		
Image Support Data			
All files supplied to user		**README.HTM; LOGO.JPG; <OE>.PDF; METADATA.DIM; IMAGERY.TIF; PREVIEW.JPG; ICON.JPG; STYLE.XSL**	

Table 2: THEOS image information (THEOS User Guide, 2009)

Level 2A images are geometrically corrected of systematic effects, e.g., panoramic effect, Earth curvature and rotation, in addition to radiometric correction. Internal distortions of the image are corrected for the imagery to be useful in measuring distances, angles, and surface areas. The imagery is projected to a standard cartographic projection (UTM WGS84 by default) using a terrain model without ground control points. (THEOS User Guide, 2009).

Physical Characteristic		Processing Specifications	
Minimum orderable area	**1 scene**	Localization accuracy	**Better than 300m RMS**
Product Framing	**Scene-based**	Radiometric corrections	**Gain/offset coefficients; radiometric calibration, missing lines**
PAN strip width	**12000-20000pixels**	Geometric corrections	**Definition of pixel size; computation of cartographic original and size; level 2A deformation model**
MS strip width	**6000-10000pixels**		
Product Parameter		Delivery parameters	
Product Options	**PAN, MS, Pan-Sharpened**	Output products delivery media options	**FTP, CD, DVD**
Number of bits/pixel in delivered product	**8 bits**	Image data format options	**GeoTIFF**
Digital scanning method	**Linear with a maximum value set to 255**	Image compression options	**High/Low**
Resampling options	**Bi cubic**		
Output pixel spacing	**2m (PAN) 15m (MS)**		
Cloud cover	**0-20%**		
Image Support Data			
All files supplied to user		**README.HTM; LOGO.JPG; <OE>.PDF; METADATA.DIM; IMAGERY.TIF; PREVIEW.JPG; ICON.JPG; STYLE.XSL**	

Table 3: THEOS image information (THEOS User Guide, 2009)

2.1. Study area and THEOS data for testing

The MARS Unit was provided with 15 (5 triplets) samples of THEOS image product, level 2A. Each triplet consists of three co-registered THEOS image products: panchromatic, pan-sharpened and multispectral. The image GeoTIFF files are accompanied by image support data, i.e. metadata in dim format which contains the product metadata under XML format, oe.pdf which is a replica of the XML style - sheet file, previrw.jpg with a quick look.The basic characteristic of our THEOS images are presented in tables 4-8.

Image ID number	SCENE T1 P 2009/04/18 10:00:40.9 0049-0262 4200	SCENE T1 M 2009/04/18 10:00:42.2 0049-0261 3299	SCENE T1 P 2009/04/18 10:00:40.9 0049-0262 4200
Image short ID	**418_PAN**	**418_M**	**418_PS**
Image product level	**2A**	**2A**	**2A**
Acquisition Date	**18 April 2009, 10:00**	**18 April 2009, 10:00**	**18 April 2009, 10:00**
Satellite incidence angle	**26.7 deg**	**26.7 deg**	**26.7 deg**
Satellite azimuth angle	**148.7 deg**	**148.7 deg**	**148.7 deg**
Viewing angle along track	**-17.2 deg**	**-17.2 deg**	**-17.2 deg**
Viewing angle across track	**-16.8 deg**	**-16.9 deg**	**-16.8 deg**
Sun azimuth	**139.8 deg**	**139.7 deg**	**139.8 deg**
Sun elevation	**50.1 deg**	**50.2 deg**	**50.1 deg**
Map Projection	**UTM: North, 31 WGS 84**		
Ellipsoid, Datum	**WGS 84**		

Table 4: Basic metadata of the THEOS triple image data acquired on 18 April 2009

Image ID number	SCENE T1 P 2009/04/22 10:23:14.0 0049-0262 8000	SCENE T1 M 2009/04/22 10:23:14.6 0049-0261 3539	SCENE T1 P 2009/04/22 10:23:14.0 0049-0262 8000
Image short ID	**422_PAN**	**422_M**	**422_PS**
Image product level	**2A**	**2A**	**2A**
Acquisition Date	**22 April 2009, 10:23**	**22 April 2009, 10:23**	**22 April 2009, 10:23**
Satellite incidence angle	**15.5 deg**	**15.5 deg**	**15.5 deg**
Satellite azimuth angle	**283.8 deg**	**283.7 deg**	**283.8 deg**
Viewing angle along track	**-0.7 deg**	**-0.7 deg**	**-0.7 deg**
Viewing angle across track	**13.7 deg**	**13.7 deg**	**13.7 deg**
Sun azimuth	**147.2 deg**	**147.2 deg**	**147.2 deg**
Sun elevation	**53.9 deg**	**54.0 deg**	**53.9 deg**
Map Projection	**UTM: North, 31 WGS 84**		
Ellipsoid, Datum	**WGS 84**		

Table 5: Basic metadata of the THEOS triple image data acquired on 22 April 2009

Image ID number	SCENE T1 P 2009/12/02 10:18:22.6 0049-02621850	SCENE T1 M 2009/12/02 10:18:22.5 0049-0262 800	SCENE T1 P 2009/12/02 10:18:22.6 0049-0262 1850
Image short ID	**202_PAN**	**202_M**	**202_PS**
Image product level	**2A**	**2A**	**2A**
Acquisition Date	**02 December 2009**	**02 December 2009**	**02 December 2009**
Satellite incidence angle	**5.0 deg**	**5.0 deg**	**5.0 deg**
Satellite azimuth angle	**282.5 deg**	**282.2 deg**	**282.5 deg**
Viewing angle along track	**-0.2 deg**	**-0.3 deg**	**-0.2 deg**
Viewing angle across track	**4.4 deg**	**4.4 deg**	**4.4 deg**
Sun azimuth	**162.0 deg**	**162.0 deg**	**162.0 deg**
Sun elevation	**22.8 deg**	**22.8 deg**	**22.8 deg**
Map Projection	**UTM: North, 31 WGS 84**		
Ellipsoid, Datum	**WGS 84**		

Table 6: Basic metadata of the THEOS triple image data acquired on 2nd December 2009

Image ID number	SCENE T1 P 2009/12/08 10:04:12.7 0049-0262 10400	SCENE T1 M 2009/12/08 10:02:57.0 0049-0261 3123	SCENE T1 P 2009/12/08 10:04:12.7 0049-026210400
Image short ID	**208_PAN**	**208_M**	**208_PS**
Image product level	**2A**	**2A**	**2A**
Acquisition Date	**08 December 2009, 10:04**	**08 December 2009, 10:02**	**08 December 2009, 10:04**
Satellite incidence angle	**37.1 deg**	**17.5 deg**	**37.1 deg**
Satellite azimuth angle	**166.0 deg**	**100.1 deg**	**166.0 deg**
Viewing angle along track	**-29.4 deg**	**-0.8 deg**	**-29.4 deg**
Viewing angle across track	**-16.0 deg**	**-15.4 deg**	**-16.0 deg**
Sun azimuth	**158.2 deg**	**158.1 deg**	**158.2 deg**
Sun elevation	**20.9 deg**	**20.8 deg**	**20.9 deg**
Map Projection	**UTM: North, 31 WGS 84**		
Ellipsoid, Datum	**WGS 84**		

Table 7: Basic metadata of the THEOS triple image data acquired on 8 December 2009

Image ID number	SCENE T1 P 2009/12/17 10:30:04.1 0049-0262 7100	SCENE T1 M 2009/12/17 10:30:04.1 0049-0262 0	SCENE T1 P 2009/12/17 10:30:04.1 0049-0262 7100
Image short ID	**217_PAN**	**217_M**	**217_PS**
Image product level	**2A**	**2A**	**2A**
Acquisition Date	**17 December 2009, 10:30**	**17 December 2009, 10:30**	**17 December 2009, 10:30**
Satellite incidence angle	**21.6 deg**	**21.6 deg**	**21.6 deg**
Satellite azimuth angle	**284.5 deg**	**284.4 deg**	**284.5 deg**
Viewing angle along track	**-1.0 deg**	**-1.0 deg**	**-1.0 deg**
Viewing angle across track	**19.0 deg**	**19.0 deg**	**19.0 deg**
Sun azimuth	**163.7 deg**	**163.7 deg**	**163.7 deg**
Sun elevation	**21.4 seg**	**21.4 deg**	**21.4 deg**
Map Projection	**UTM: North, 31 WGS 84**		
Ellipsoid, Datum	**WGS 84**		

Table 8: Basic metadata of the THEOS triple image data acquired on 17 December 2009

The above listed THEOS images (tab.4-8) were acquired over the JRC Maussane test site which is located near to Mausanne-les-Alpilles in France. It has been used as test site by the European Commission Joint Research Centre since 1997. It comprises a time series of reference data (i.e. DEMs, imagery, and ground control) and presents a variety of agricultural conditions typical for the EU. The site contains a low mountain massif (elevation up to around 650m above sea level), mostly covered by forest, surrounded by low lying agricultural plains and a lot of olive groves. A number of low density small urban settlements and a few limited water bodies are present over the site.

The location of the sample THEOS images over the Maussane test site is presented in figures 1 and 2.

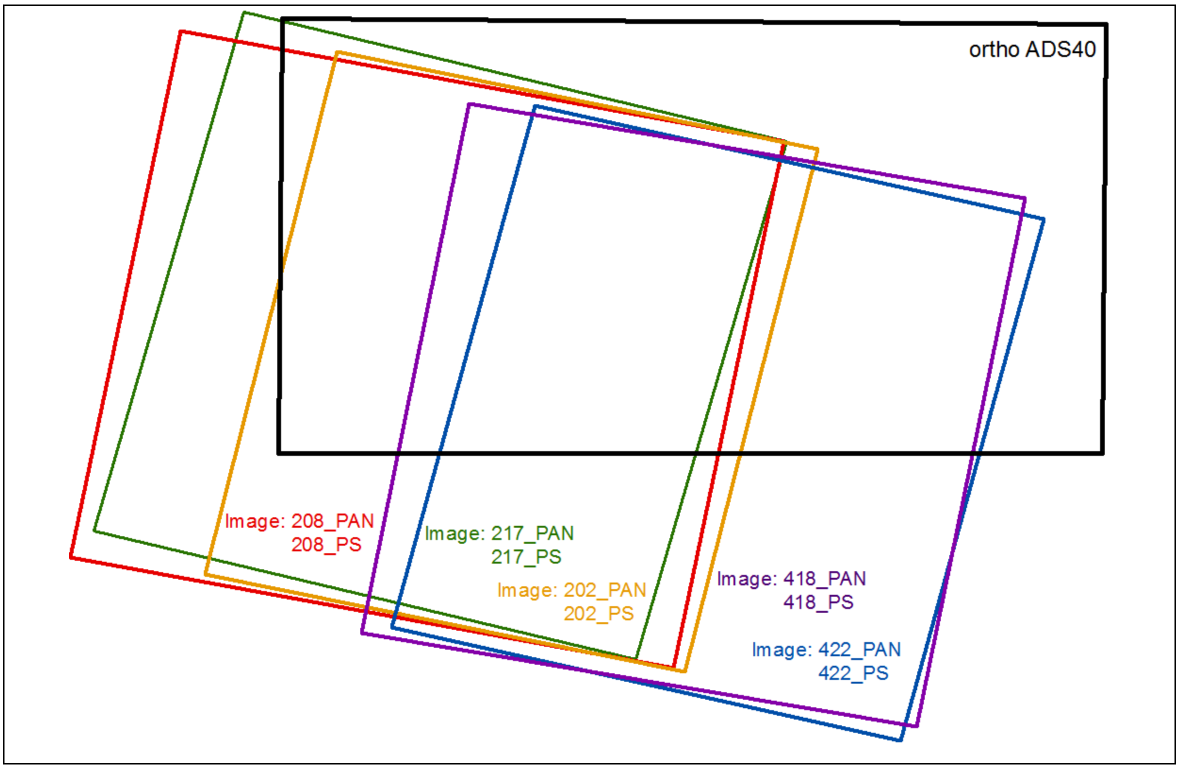

Figure 1: The location of the THEOS sample images (PAN, PS) and the JRC Maussane Test Site covered by reference aerial ADS40 orthoimagery.

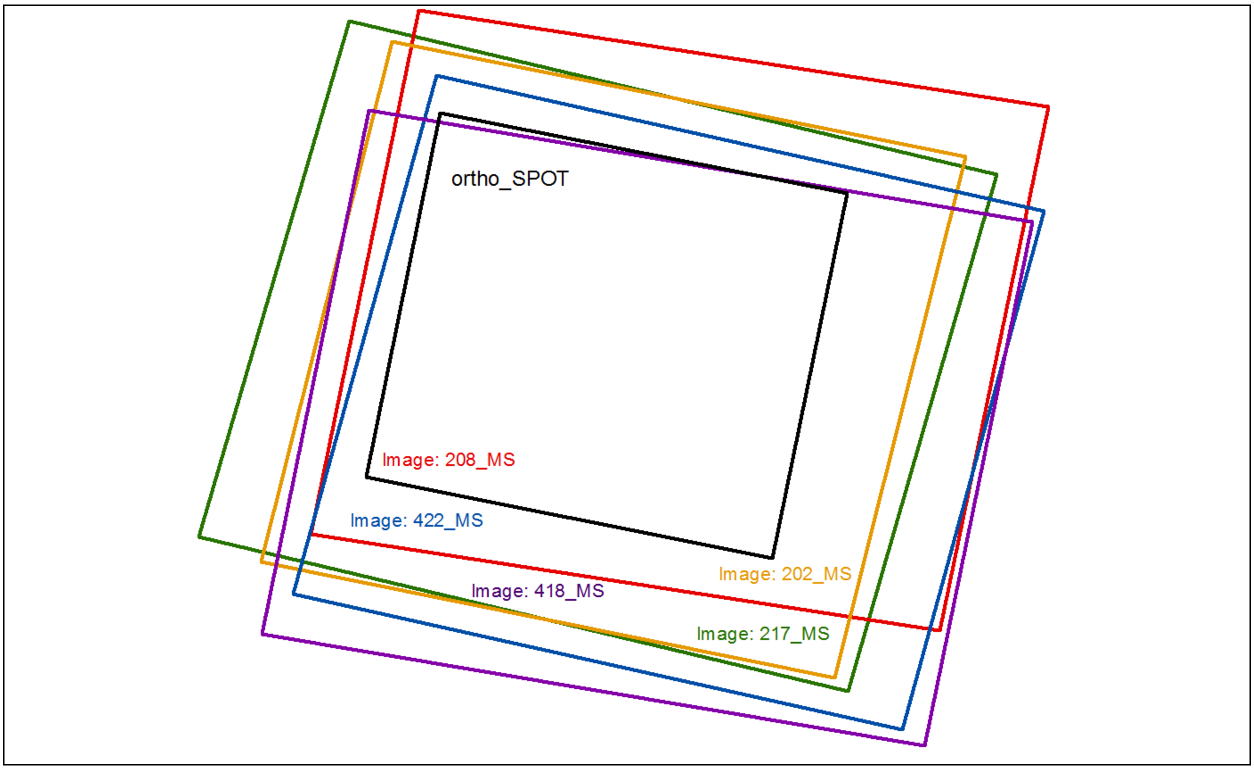

Figure 2: The location of the THEOS sample images (MS) and the reference SPOT orthoimage acquired over JRC Maussane Test Site.

2.4. Validation Data

The following data was used during the absolute and relative accuracy estimation of the THEOS images 418_PAN and 418_PS:

<table>
<tr><th rowspan="2">Image</th><th colspan="2">418_PAN and 418_PS</th></tr>
<tr><th>ICPsSet1- Absolute</th><th>ICPs Set2 - Relative</th></tr>
<tr><td>418_PAN</td><td rowspan="2">Sets of 5 IPCs from multi-use project:
RMSEx=0.30; RMSEy=0.30
66014, 66023, 66027, 66028, 66035;

Sets of 1 IPC from Vexel project RMSEx=0.49m; RMSEy=0.50m
440008;

Sets of 2 IPCs from Cartosat-1 project
RMSEx=0.55m, RMSEy=0.37m
330006, 330012;

Sets of 4 IPCs from Cartosat-2 project
RMSEx=0.88m, RMSEy=0.72m
G7001, G7023, G7034, G7037;

Sets of 2 IPCs from ADS40 project
RMSEx<0.05m, RMSEy=0.1m 110031,110035

Average RMSEx,y of 0.4m</td><td rowspan="2">Sets of 16 IPCs chosen and measured on the aerial ADS40 ortho:
RMSEx = 0.88m;
RMSEy = 0.72m

990008, 990025, 990030, 990032, PS_PAN_4, PS_PAN_7, PS_PAN_9, PS_PAN_10, PS_PAN_11, PS_PAN_13, PS_PAN_14, PS_PAN_15, PS_PAN_17, PS_PAN_19, PS_PAN_21, PS_PAN_23</td></tr>
<tr><td>418_PS</td></tr>
</table>

Table 9: ICPs using during the absolute and relative estimation (PAN, PS)

The following data was used during estimation of the absolute and relative accuracy of the THEOS images 418_MS.

Image	ICPs Set3 for 418_MS Relative Accuracy Check
418_MS	Sets of 24 IPCs chosen and measured on the SPOT ortho: **3.3m < RMSEx,y < 5.5m**; MS_1, MS_4, MS_5, MS_6, MS_7, MS_8, MS_9, MS_10, MS_11, MS_14, MS_15, MS_16, MS_17, MS_18, MS_20, MS_21, MS_22, MS_23, MS_24, MS_25, MS_26, MS_27, MS_28, MS_30

Table 10: ICPs using during the relative estimation (MS)

The following data was used during the absolute and relative accuracy estimation of the THEOS images 422_PAN and 422_PS.

<table>
<tr><th rowspan="2">Image</th><th colspan="2">422_PAN and 422_PS</th></tr>
<tr><th>ICPsSet1- Absolute</th><th>ICPsSet2 - Relative</th></tr>
<tr><td>422_PAN</td><td rowspan="2">Sets of 2 IPCs from multi-use project:
RMSEx=0.30; RMSEy=0.30
66014, 66035;

Sets of 1 IPC from Vexel project RMSEx=0.49m; RMSEy=0.50m
440004;

Sets of 1 IPC from Cartosat-1 project RMSEx=0.55m, RMSEy=0.37m
330006;

Sets of 4 IPCs from Cartosat-2 project RMSEx = 0.88m; RMSEy = 0.72m
G7021, G7023, G7027, G7034;

Sets of 5 IPCs from ADS40 project RMSEx<0.05m, RMSEy=0.01m
110021, 110031, 110035, 110036, 110040;

Sets of 1 IPC from Formosat-2 project RMSEx=0.88m, RMSEy=0,72m
550015

Average RMSEx,y of 0.4m</td><td rowspan="2">Sets of 16 IPCs chosen and measured on the aerial ADS40 ortho:
RMSEx = 0.88m;
RMSEy = 0.72m

990025, 990030, 990032, 990051, PS_PAN_3, PS_PAN_4, PS_PAN_6, PS_PAN_7, PS_PAN_8, PS_PAN_15, PS_PAN_17, PS_PAN_19, PS_PAN_21, PS_PAN_22, PS_PAN_23, PS_PAN_24</td></tr>
<tr><td>422_PS</td></tr>
</table>

Table 11: ICPs using during the absolute and relative estimation (PAN, PS)

The following data was used during estimate of absolute and relative accuracy of the THEOS images 422_MS.

Image	ICPs Set3 for 422_MS Relative Accuracy Check
422_MS	Sets of 24 IPCs chosen and measured on the SPOT ortho: **3.3m < RMSEx,y < 5.5m**; MS_1, MS_4, MS_5, MS_6, MS_7, MS_8, MS_9, MS_10, MS_12, MS_14, MS_15, MS_16, MS_17, MS_18, MS_20, MS_21, MS_22, MS_23, MS_24, MS_25, MS_26, MS_27, MS_28, MS_30

Table 12: ICPs using during the relative estimation (MS)

The following data was used during the absolute and relative accuracy estimation of the THEOS images 202_PAN and 202_PS.

<table>
<tr><th rowspan="2">Image</th><th colspan="2">202_PAN and 202_PS</th></tr>
<tr><th>ICPsSet1- Absolute</th><th>ICPsSet2 - Relative</th></tr>
<tr><td>202_PAN</td><td rowspan="2">Sets of 6 IPCs from multi-use project:
RMSEx=0.30; RMSEy=0.30
66015, 66021, 66022, 66023, 66027, 66035;

Sets of 1 IPC from Vexel project RMSEx=0.49m; RMSEy=0.50m
440008;

Sets of 2 IPCs from Cartosat-1 project RMSEx=0.55m, RMSEy=0.37m
330007, 330013;

Sets of 3 IPCs from Cartosat-2 project RMSEx = 0.88m; RMSEy = 0.72m
G7001, G7023, G7034;

Sets of 2 IPCs from ADS40 project RMSEx<0.05m, RMSEy=0.01m
110002, 110021

Average RMSEx,y of 0.4m</td><td rowspan="2">Sets of 16 IPCs chosen and measured on the aerial ADS40 ortho:

RMSEx = 0.88m; RMSEy = 0.72m

990008, 990019, 990025, 990030, 990032, 990047, 990051, PS_PAN_5, PS_PAN_6, PS_PAN_8, PS_PAN_15, PS_PAN_16, PS_PAN_17, PS_PAN_19, PS_PAN_20, PS_PAN_21</td></tr>
<tr><td>202_PS</td></tr>
</table>

Table 13: ICPs using during the absolute and relative estimation (PAN, PS)

The following auxiliary data was used during estimate of absolute and relative accuracy of the THEOS images 202_MS

Image	ICPs Set3 for 202_MS Relative Accuracy Check
202_MS	Sets of 24 IPCs chosen and measured on the SPOT ortho: **3.3m < RMSEx,y < 5.5m**; MS_2, MS_4, MS_5, MS_6, MS_7, MS_8, MS_9, MS_10, MS_11, MS_12, MS_13, MS_15, MS_16, MS_17, MS_18, MS_19, MS_21, MS_22, MS_23, MS_24, MS_25, MS_28, MS_29, MS_30

Table 14: ICPs using during the relative estimation (MS)

The following data was used during the absolute and relative accuracy estimation of the THEOS images 208_PAN and 208_PS.

<table>
<tr><th rowspan="2">Image</th><th colspan="2">208_PAN and 208_PS</th></tr>
<tr><th>ICPsSet1- Absolute</th><th>ICPsSet2 - Relative</th></tr>
<tr><td>208_PAN</td><td rowspan="2">Sets of 7 IPCs from multi-use project:
RMSEx=0.30; RMSEy=0.30
66016, 66021, 66022, 66023, 66026, 66028, 66035;

Sets of 1 IPC from Vexel project
RMSEx=0.49m; RMSEy=0.50m
440008;

Sets of 2 IPCs from Cartosat-1 project
RMSEx=0.55m, RMSEy=0.37m
330007, 330013;

Sets of 3 IPCs from Cartosat-2 project
RMSEx=0.88m, RMSEy=0.72m
G7001, G7023, G7034;

Sets of 1 IPC from ADS40 project
RMSEx<0.05m, RMSEy=0.01m
110002

Average RMSEx,y of 0.4m</td><td rowspan="2">Sets of 16 IPCs chosen and measured on the aerial ADS40 ortho:

RMSEx = 0.88m; RMSEy = 0.72m

990008, 990022, 990025, 990030, 990032, 990047, 990051, PS_PAN_2, PS_PAN_8, PS_PAN_15, PS_PAN_16, PS_PAN_17, PS_PAN_19, PS_PAN_20, PS_PAN_21, PS_PAN_22</td></tr>
<tr><td>208_PS</td></tr>
</table>

Table 15: ICPs using during the absolute and relative estimation (PAN, PS)

The following data was used during estimate of absolute and relative accuracy of the THEOS images 208_MS.

Image	ICPs Set3 for 208_MS Relative Accuracy Check
208_MS	Sets of 24 IPCs chosen and measured on the SPOT ortho: **3.3m < RMSEx,y < 5.5m**; MS_2, MS_3, MS_5, MS_6, MS_7, MS_8, MS_9, MS_10, MS_11, MS_12, MS_14, MS_15, MS_16, MS_17, MS_18, MS_19, MS_20, MS_21, MS_22, MS_23, MS_24, MS_25, MS_28, MS_30

Table 16: ICPs using during the relative estimation (MS)

The following auxiliary data was used during the absolute and relative accuracy estimation of the THEOS images 217_PAN and 217_PS.

<table>
<tr><th rowspan="2">Image</th><th colspan="2">217_PAN and 217_PS</th></tr>
<tr><th>ICPsSet1- Absolute</th><th>ICPsSet2 - Relative</th></tr>
<tr><td>217_PAN</td><td rowspan="2">Sets of 4 IPCs from multi-use project:
RMSEx=0.30; RMSEy=0.30
66022, 66023, 66027, 66035;

Sets of 2 IPCs from Vexel project
RMSEx=0.49m; RMSEy=0.50m
440008, 440024;

Sets of 2 IPCs from Cartosat-1 project
RMSEx=0.55m, RMSEy=0.37m
330007, 330013;

Sets of 2 IPCs from Cartosat-2 project
RMSEx=0.88m, RMSEy=0.72m
G7001, G7034;

Sets of 2 IPCs from ADS40 project
RMSEx<0.05m, RMSEy=0.01m
110002, 110021, 110036;

Sets of 1 IPC from Formosat-2 project
RMSEx=0.88m, RMSEy=0,72m
550009

Average RMSEx,y of 0.4m</td><td rowspan="2">Sets of 16 IPCs chosen and measured on the aerial ADS40 ortho:

RMSEx = 0.88m; RMSEy = 0.72m

990008, 990019, 990022, 990025, 990030, 990032, 990047, 990051, PS_PAN_1, PS_PAN_2, PS_PAN_8, PS_PAN_15, PS_PAN_16, PS_PAN_17, PS_PAN_18, PS_PAN_19</td></tr>
<tr><td>217_PS</td></tr>
</table>

Table 17: ICPs using during the absolute and relative estimation (PAN, PS)

The following auxiliary data was used during estimate of absolute and relative accuracy of the THEOS images 217_MS

Image	ICPs Set3 for 217_MS Relative Accuracy Check
217_MS	Sets of 24 IPCs chosen and measured on the SPOT ortho: **3.3m < RMSEx,y < 5.5m**; MS_1, MS_2, MS_4, MS_5, MS_6, MS_7, MS_8, MS_9, MS_10, MS_11, MS_14, MS_15, MS_16, MS_17, MS_18, MS_19, MS_20, MS_21, MS_22, MS_23, MS_24, MS_25, MS_28, MS_30

Table 18: ICPs using during the relative estimation (MS)

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

3. Methodology

3.1. Methodology overview

THEOS products are characterised by two different correction levels including system corrected level (1A) and geo - corrected level (2A). The JRC and the authors of this report were provided with THEOS level 2A images that are geometrically corrected of systematic effects and projected to a standard cartographic projection (UTM WGS84 by default) using a terrain model (without GCPs). Unfortunately this product differs from the Ortho Ready Standard Imagery that has no topographic relief applied, making it suitable for custom orthorectification.

In order to evaluate the geometric characteristics of the 2A THEOS 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 check points).
The RMS error calculated for independent check points (ICPs) in each dimension (either Easting or Northing) is used to describe the required product accuracy (also referred to as 1-D RMSE).
The external quality control results allowed also analysing the relationship between the THEOS satellite incidence angle and the THEOS image products' geometric quality.

The final absolute product accuracy was calculated for five panchromatic and pan-sharpening THEOS 2A products based on a set of 14 accurate points measured by DGPS.
Additionally, the relative THEOS 2A PAN or PS product accuracy was calculated for five panchromatic and pan-sharpening THEOS 2A products based on a set of 16 chosen from the aerial ADS40 orthoimagery characterised by 0.5m resolution.

In case of the THEOS 2A multispectral imagery (ground sampling distance of 15m), the reference points (ICPs) were chosen on the SPOT PAN orthoimage of 2.5m spatial resolution. The final one dimensional RMS error of the THEOS 2A MS accuracy was calculated based on manual measurement of the 24 ICPs (SPOT-based). Since the absolute positions of these 24 check points are not known, the result is relative to the SPOT orthoimage accuracy.

The THEOS sensor was also analysed by Swedish company, Spacemetric, using their own digital photogrammetric software called Keystone. GISTDA, the THEOS image provider, supplied Spacemetric with panchromatic and multispectral THEOS imagery of processing level 1A (without the JRC mediation). Spacemetric performed THEOS sensor modelling and orthorectification using the Keystone matching techniques for GCP and ICP choice and measurement. Swedish company obtained very promising results (see chapters 4.6 and 4.7). It should be borne in mind, however, that these results are relative values to the reference orthoimages, i.e. ortho ADS40 or Landsat7 for PAN and MS respectively.

Spacemetric provided the JRC with their final THEOS orthoimages, therefore we could perform the external quality control using our set of ICPs (see chapters 4.3 – 4.5), and compare the results (see chapter 5.5).

3.2. THEOS Sensor Support

At the time of the THEOS image geometry testing, the available ERDAS Imagine and LPS 10.3 version and PCI Geomatics 10.3.0 version supported only rigorous THEOS sensor model that requires 1A level of processing image (that we were not provide with). According to the ERDAS Support Team the RPC-based THEOS model will be implemented in future provided a commercial demand for this sensor model occurs.

3.3. Tested variants

We analysed absolute and relative accuracy of the provided THEOS panchromatic, multispectral and pan-sharpened images.

Image	Number of IPC	List of IPCs
418_PAN 418_PS	14	66014, 66023, 66027, 66028, 66035, 440008, 330006, 330012, G7001, G7023, G7034, G7037, 10031,110035
422_PAN 422_PS	14	66014, 66035,440004, 330006, G7021, G7023, G7027, G7034, 110021, 110031, 110035, 110036, 110040, 550015
202_PAN 202_PS	14	66015, 66021, 66022, 66023, 66027, 66035, 440008, 330007, 330013, G7001, G7023, G7034, 110002, 110021
208_PAN 208_PS	14	66016, 66021, 66022, 66023, 66026, 66028, 66035, 440008, 330007, 330013, G7001, G7023, G7034, 110002
217_PAN 217_PS	14	66022, 66023, 66027, 66035, 440008, 440024, 330007, 330013, G7001, G7034,110002, 110021, 110036, 550009

Table 19: The list of ICPs for THEOS PAN and PS absolute accuracy estimation

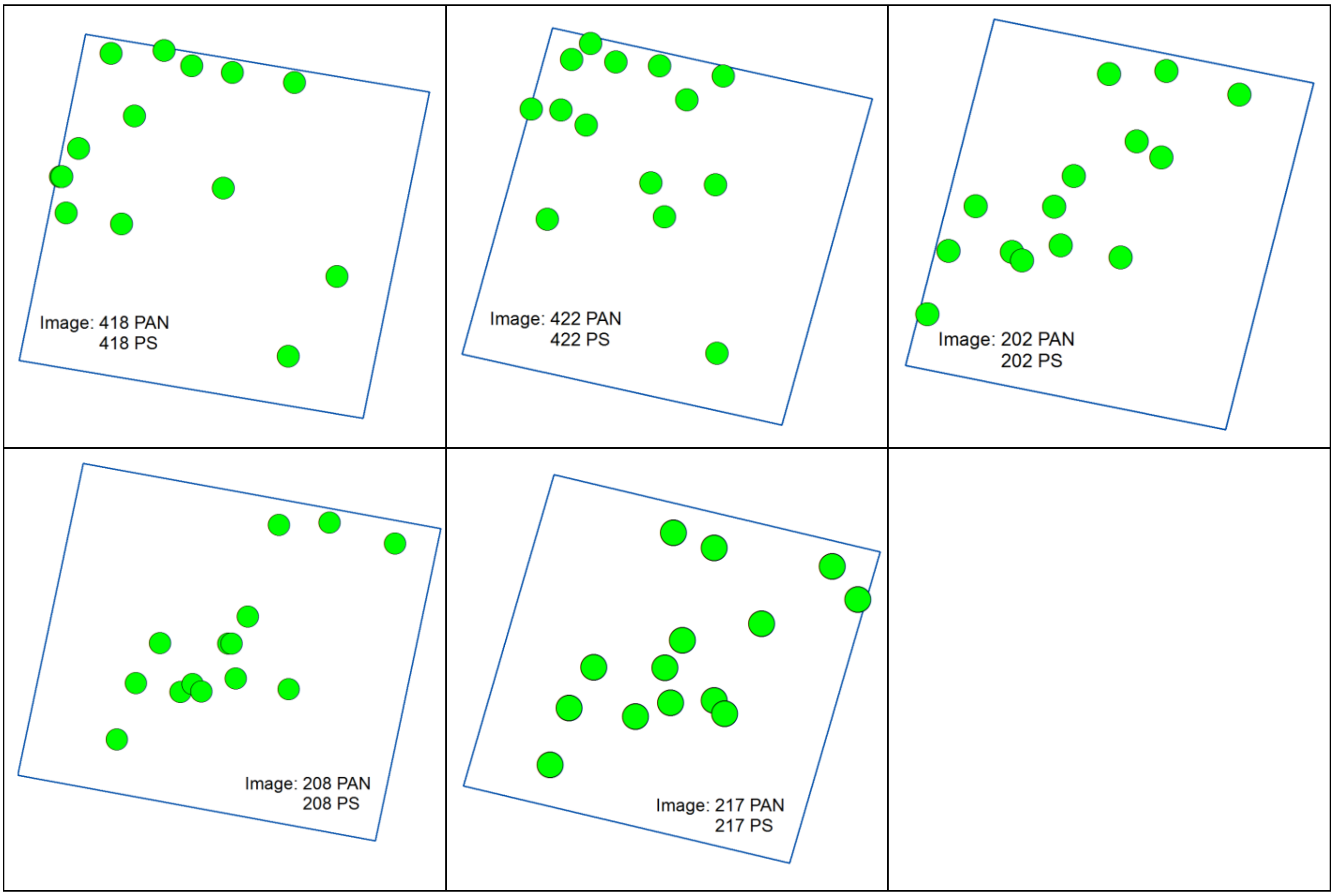

Figure 3: Sets of the 14 independent check points (ICPs) for absolute accuracy estimation of THEOS PAN and PS images.

Image	Number of IPCs	List of IPCs
418_PAN 418_PS	14	990008, 990025, 990030, 990032, PS_PAN_4, PS_PAN_7, PS_PAN_9, PS_PAN_10, PS_PAN_11, PS_PAN_13, PS_PAN_14, PS_PAN_15, PS_PAN_17, PS_PAN_19, PS_PAN_21, PS_PAN_23
422_PAN 422_PS	14	990025, 990030, 990032, 990051, PS_PAN_3, PS_PAN_4, PS_PAN_6, PS_PAN_7, PS_PAN_8, PS_PAN_15, PS_PAN_17, PS_PAN_19, PS_PAN_21, PS_PAN_22, PS_PAN_23, PS_PAN_24
202_PAN 202_PS	14	990008, 990019, 990025, 990030, 990032, 990047, 990051, PS_PAN_5, PS_PAN_6, PS_PAN_8, PS_PAN_15, PS_PAN_16, PS_PAN_17, PS_PAN_19, PS_PAN_20, PS_PAN_21
208_PAN 208_PS	14	990008, 990022, 990025, 990030, 990032, 990047, 990051, PS_PAN_2, PS_PAN_8, PS_PAN_15, PS_PAN_16, PS_PAN_17, PS_PAN_19, PS_PAN_20, PS_PAN_21, PS_PAN_22
217_PAN 217_PS	14	990008, 990019, 990022, 990025, 990030, 990032, 990047, 990051, PS_PAN_1, PS_PAN_2, PS_PAN_8, PS_PAN_15, PS_PAN_16, PS_PAN_17, PS_PAN_18, PS_PAN_19

Table 20: The list of ICPs for THEOS PAN and PS relative accuracy estimation

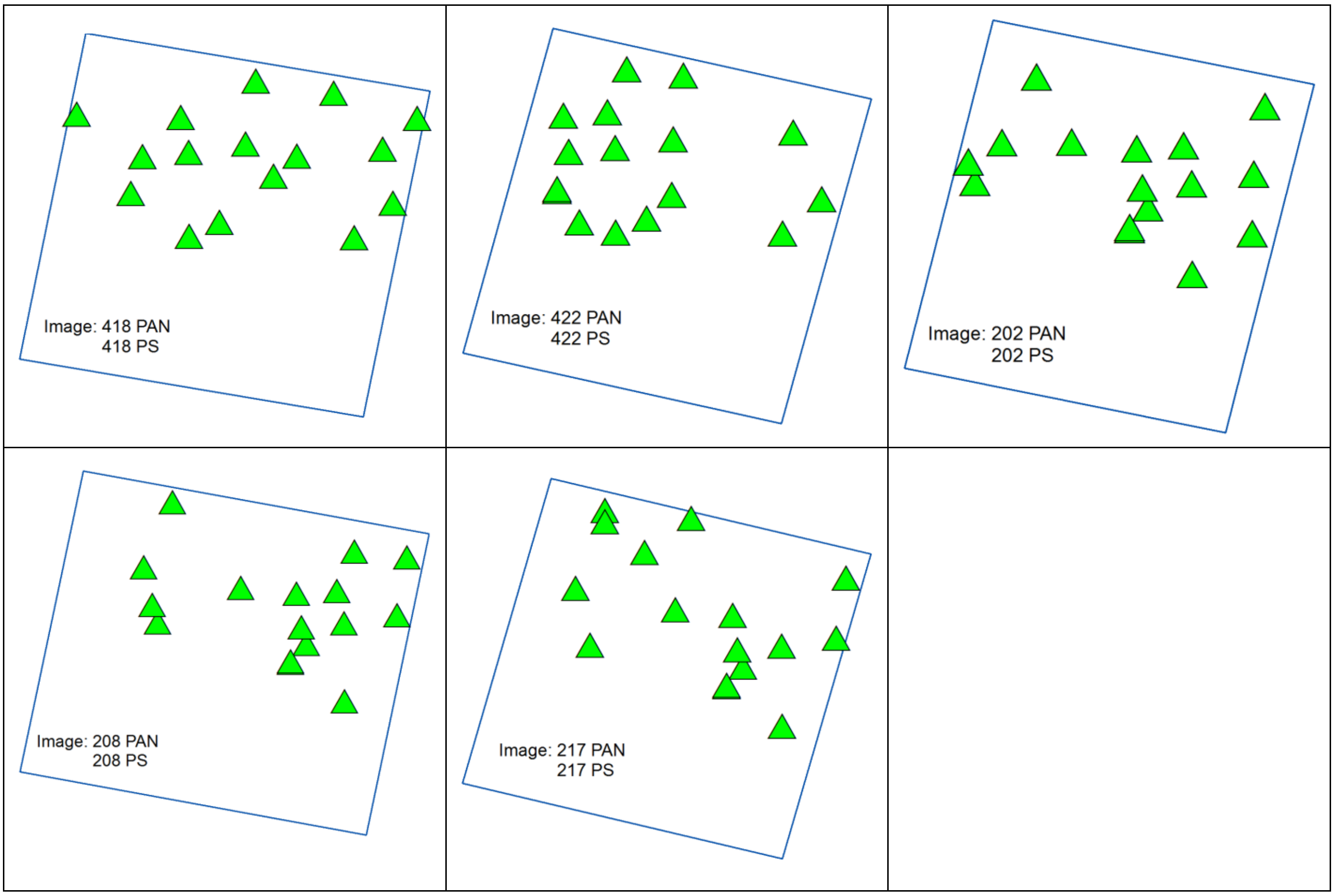

Figure 4: Sets of the 14 independent check points (ICPs) for relative accuracy estimation of THEOS PAN and PS images

Image	Number of IPC	List of IPCs
418_MS	*24*	MS_1, MS_4, MS_5, MS_6, MS_7, MS_8, MS_9, MS_10, MS_11, MS_14, MS_15, MS_16, MS_17, MS_18, MS_20, MS_21, MS_22, MS_23, MS_24, MS_25, MS_26, MS_27, MS_28, MS_30
422_MS	*24*	MS_1, MS_4, MS_5, MS_6, MS_7, MS_8, MS_9, MS_10, MS_12, MS_14, MS_15, MS_16, MS_17, MS_18, MS_20, MS_21, MS_22, MS_23, MS_24, MS_25, MS_26, MS_27, MS_28, MS_30
202_MS	*24*	MS_2, MS_4, MS_5, MS_6, MS_7, MS_8, MS_9, MS_10, MS_11, MS_12, MS_13, MS_15, MS_16, MS_17, MS_18, MS_19, MS_21, MS_22, MS_23, MS_24, MS_25, MS_28, MS_29, MS_30
208_MS	*24*	MS_2, MS_3, MS_5, MS_6, MS_7, MS_8, MS_9, MS_10, MS_11, MS_12, MS_14, MS_15, MS_16, MS_17, MS_18, MS_19, MS_20, MS_21, MS_22, MS_23, MS_24, MS_25, MS_28, MS_30
217_MS	*24*	MS_1, MS_2, MS_4, MS_5, MS_6, MS_7, MS_8, MS_9, MS_10, MS_11, MS_14, MS_15, MS_16, MS_17, MS_18, MS_19, MS_20, MS_21, MS_22, MS_23, MS_24, MS_25, MS_28, MS_30

Table 21: The list of ICPs for THEOS MS relative accuracy estimation

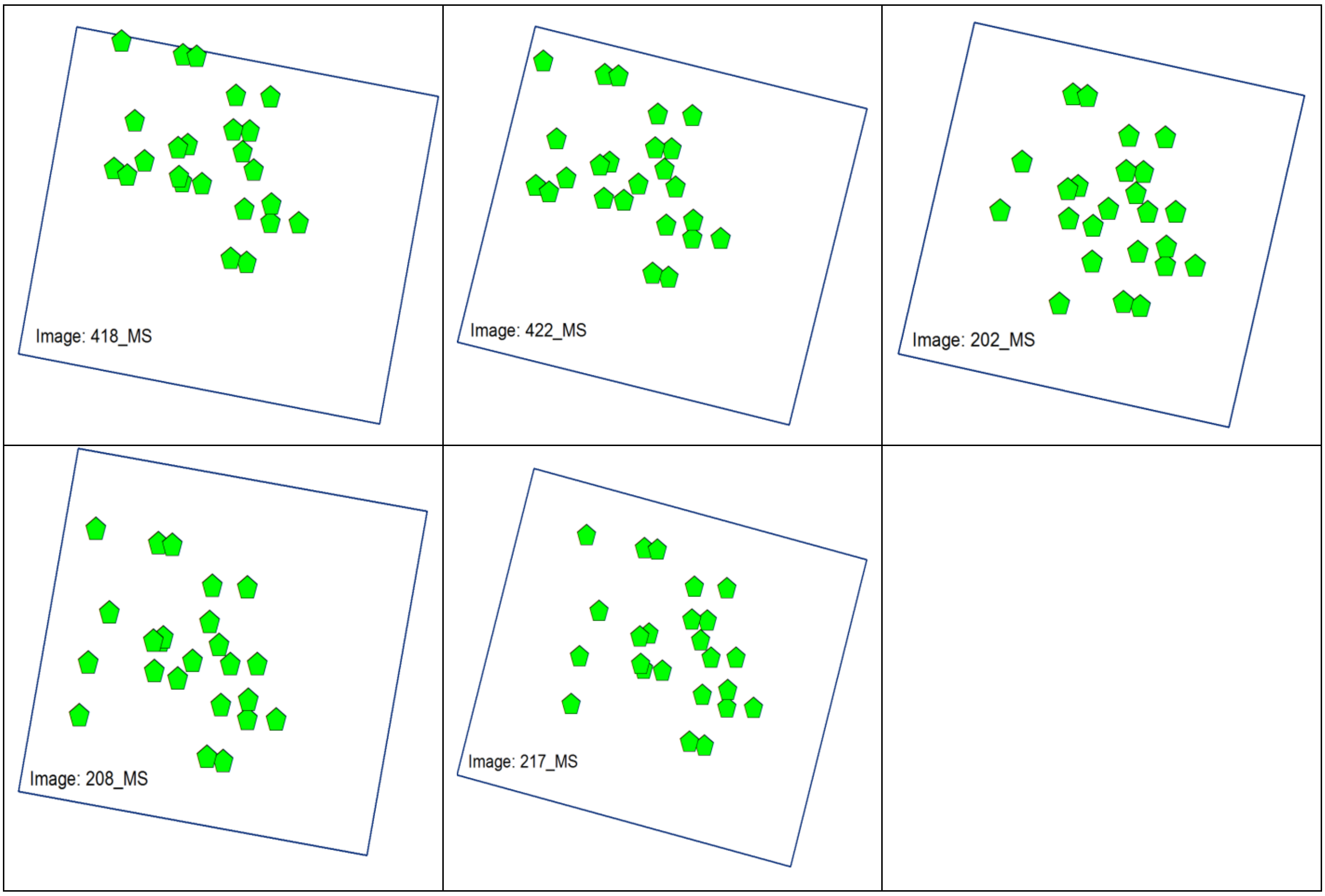

Figure 5: Configurations of the 24 independent check points (ICPs) for relative accuracy estimation of THEOS MS images

4. Results

4.1. 2A THEOS PAN and PS quality analysis – absolute accuracy

With using IPCs from GPS measurements we obtain the following RMSE results [in meters] for absolute accuracy before and after systematic error elimination, summarised in the Table 22-23:

	RMSE	No of ICPs	20090418	20090422	20091202	20091208	20091217	average
PAN	E	14 (set1)	**173.36**	**69.47**	**36.00**	**251.99**	**130.08**	**132**
	N		**77.19**	**123.78**	**18.72**	**7.84**	**196.27**	**85**
PS	E	14 (set1)	**173.32**	**69.56**	**36.28**	**250.49**	**130.49**	**132**
	N		**77.51**	**123.67**	**18.81**	**8.01**	**196.29**	**85**

Table 22: 2A THEOS absolute accuracy before systematic error elimination

	RMSE	No of ICPs	20090418	20090422	20091202	20091208	20091217	average
PAN	E	14 (set1)	**14.43**	**3.74**	**3.78**	**2.56**	**4.18**	**6**
	N		**7.54**	**2.94**	**3.21**	**7.74**	**3.45**	**5**
PS	E	14 (set1)	**14.42**	**3.62**	**3.48**	**5.13**	**4.19**	**6**
	N		**7.37**	**2.86**	**3.13**	**7.94**	**3.45**	**5**

Table 23: 2A THEOS absolute accuracy after systematic error elimination

4.2. 2A THEOS Products quality analysis - relative accuracy

With using IPCs from ortho ADS40 for PAN, PS and IPCs from ortho SPOT for MS we obtained the following RMSE results for absolute accuracy before and after systematic error elimination summarised in the Table 24-25:

	RMSE	No of ICPs	20090418	20090422	20091202	20091208	20091217	average
PAN	E	16 (set2)	**177.97**	**72.69**	**35.20**	**252.96**	**129.58**	**134**
	N		**80.18**	**124.46**	**19.97**	**14.04**	**196.20**	**87**
PS	E	16 (set2)	**177.88**	**72.93**	**35.13**	**252.86**	**129.54**	**134**
	N		**79.92**	**124.22**	**20.56**	**14.20**	**196.44**	**87**
MS	E	24 (set3)	**170.48**	**79.43**	**50.72**	**7.12**	**141.84**	**90**
	N		**78.21**	**116.54**	**15.19**	**190.07**	**194.64**	**119**

Table 24: 2A THEOS relative accuracy before systematic error elimination

	RMSE	No of ICPs	20090418	20090422	20091202	20091208	20091217	average
PAN	E	16 (set2)	**5.90**	**2.74**	**1.95**	**4.53**	**4.11**	**4**
	N		**7.74**	**3.25**	**4.32**	**13.93**	**4.48**	**7**
PS	E	16 (set2)	**5.71**	**2.98**	**1.97**	**4.09**	**3.88**	**4**
	N		**7.86**	**3.15**	**4.37**	**14.19**	**4.65**	**7**
MS	E	24 (set3)	**8.85**	**7.59**	**9.09**	**7.02**	**9.59**	**8**
	N		**5.32**	**12.58**	**13.56**	**10.65**	**12.89**	**11**

Table 25: 2A THEOS relative accuracy after systematic error elimination

4.3. THEOS PAN orthoimage (by Spacemetric) quality analysis – relative accuracy

	RMSE	Number of points	20091202 TH_CAT_100104060755624_1	20091208 TH_CAT_100104065641103_1	20091217 TH_CAT_100104065822594_1	average
PAN	E	16 (set2)	**1.38**	**2.35**	**1.48**	**2**
	N		**2.41**	**3.47**	**1.81**	**3**

Table 26: External Quality Control results on PAN orthoimage produced from 1A by Spacemetric – relative accuracy

4.4. THEOS MS orthoimage (by Spacemetric) quality analysis – relative accuracy

	RMSE	Number of points	20091202 TH_CAT_100104070547986_1	20091208 TH_CAT_100125070936541_1	20091217 TH_CAT_100104072207474_1	average
MS	E	24 (set3)	**7.05**	**6.50**	**5.01**	**6**
	N		**25.91**	**25.28**	**24.81**	**25**

Table 27: External Quality Control results on MS orthoimage produced from 1A by Spacemetric – relative accuracy before systematic error elimination

	RMSE	Number of points	20091202 TH_CAT_100104070547986_1	20091208 TH_CAT_100125070936541_1	20091217 TH_CAT_100104072207474_1	average
MS	E	24 (set3)	**6.73**	**6.47**	**4.86**	**6**
	N		**7.19**	**4.16**	**5.48**	**6**

Table 28: External Quality Control results on MS orthoimage produced from 1A by Spacemetric – relative accuracy after systematic error elimination

4.5. THEOS PAN orthoimage (by Spacemetric) quality analysis – absolute accuracy

	RMSE	Number of points	20091202 TH_CAT_100104060755624_1	20091208 TH_CAT_100104065641103_1	20091217 TH_CAT_100104065822594_1	average
PAN	E	16 (set1)	**1.62**	**2.45**	**1.55**	**2**
	N		**1.10**	**4.16**	**1.70**	**2**

Table 29: External Quality Control results on PAN orthoimage produced from 1A by Spacemetric – absolute accuracy

4.6. THEOS PAN orthoimage produced and validated by Spacemetric – relative accuracy

	RMSE	Number of points	20091202 TH_CAT_100104060755624_1	20091208 TH_CAT_100104065641103_1	20091217 TH_CAT_100104065822594_1	average
PAN	E	9	**1.1**	**0.9**	**1.2**	**1**
	N		**0.8**	**1.4**	**1.0**	**1**

Table 30: External Quality Control results on PAN orthoimage produced from 1A by Spacemetric – relative accuracy

4.7. THEOS MS orthoimage produced and validated by Spacemetric – relative accuracy

	RMSE	Number of points	20091202 TH_CAT_100104070547986_1	20091208 TH_CAT_100125070936541_1	20091217 TH_CAT_100104072207474_1	average
MS	E	9	**4.4**	**4.1**	**4.7**	**4**
	N		**6.6**	**5.8**	**2.9**	**5**

Table 31: External Quality Control results on MS orthoimage produced from 1A by Spacemetric –relative accuracy

5. Discussion

5.1. 2A THEOS Products Absolute and Relative Accuracy

The results of the absolute and relative accuracy for PAN, PS, MS imagery, before systematic error elimination is presented in figures 6-8:

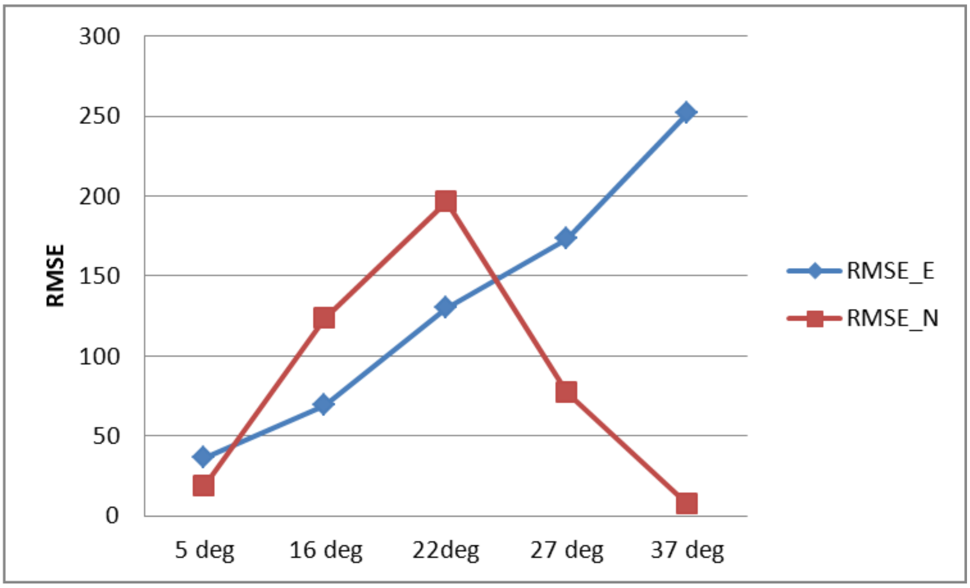

Figure 6: Before systematic error elimination, absolute accuracy (PAN, PS)

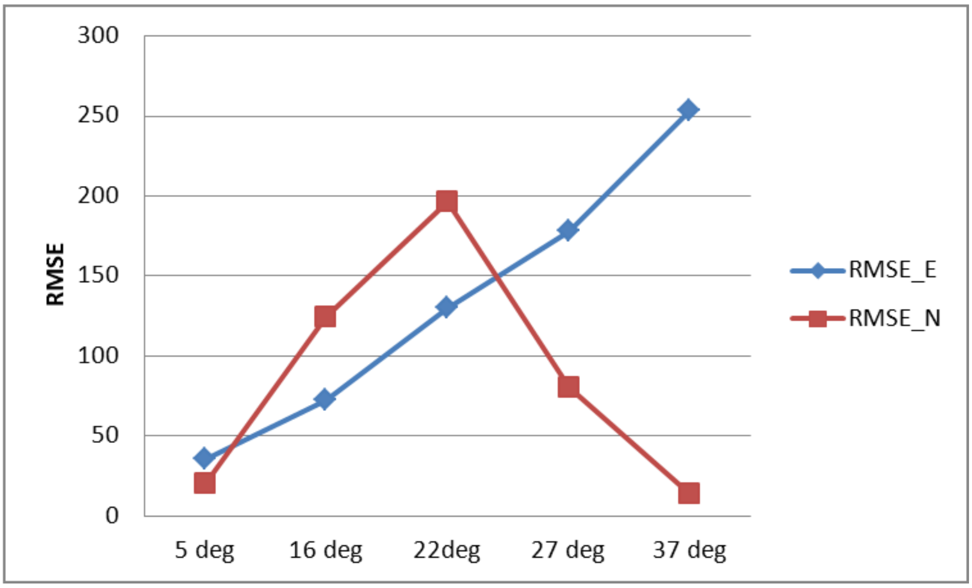

Figure 7: Before systematic error elimination, relative accuracy (PAN, PS)

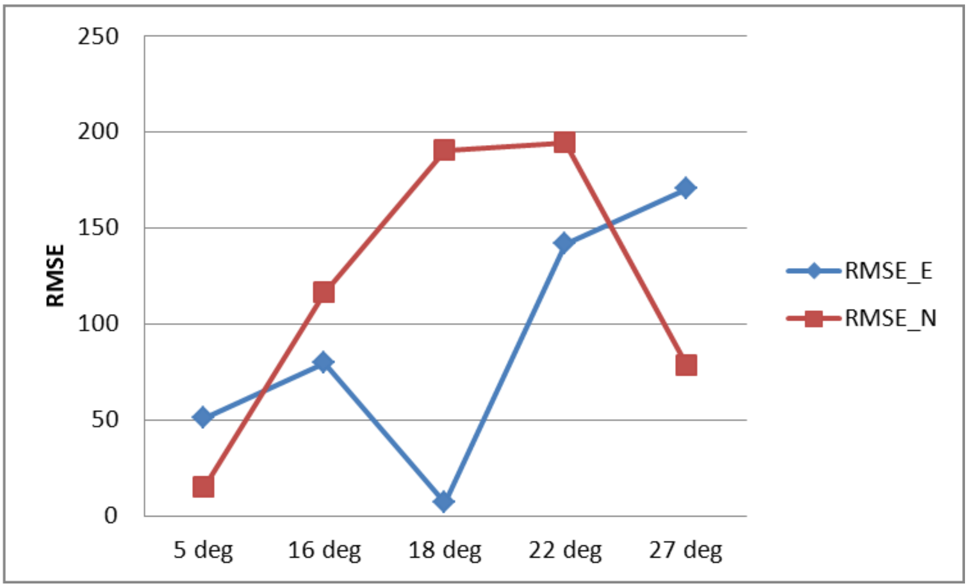

Figure 8: Before systematic error elimination, relative accuracy (MS)

5.2. 2A THEOS Products Absolute and Relative Accuracy after systematic error elimination

The results of the absolute and relative accuracy for PAN, PS, MS imagery, after systematic error elimination is presented in figures 9-11:

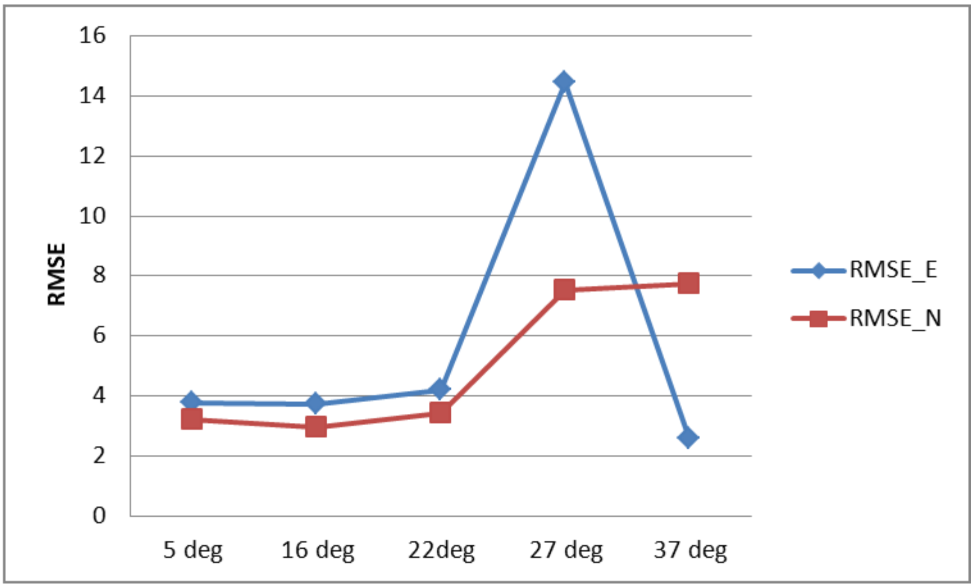

Figure 9: After systematic error elimination, absolute accuracy (PAN, PS)

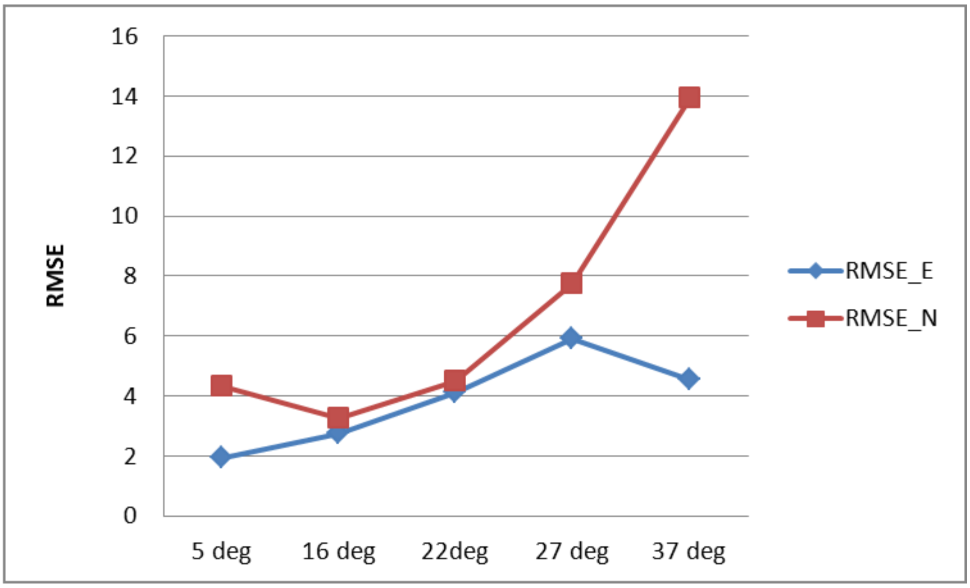

Figure 10: After systematic error elimination, relative accuracy (PAN, PS)

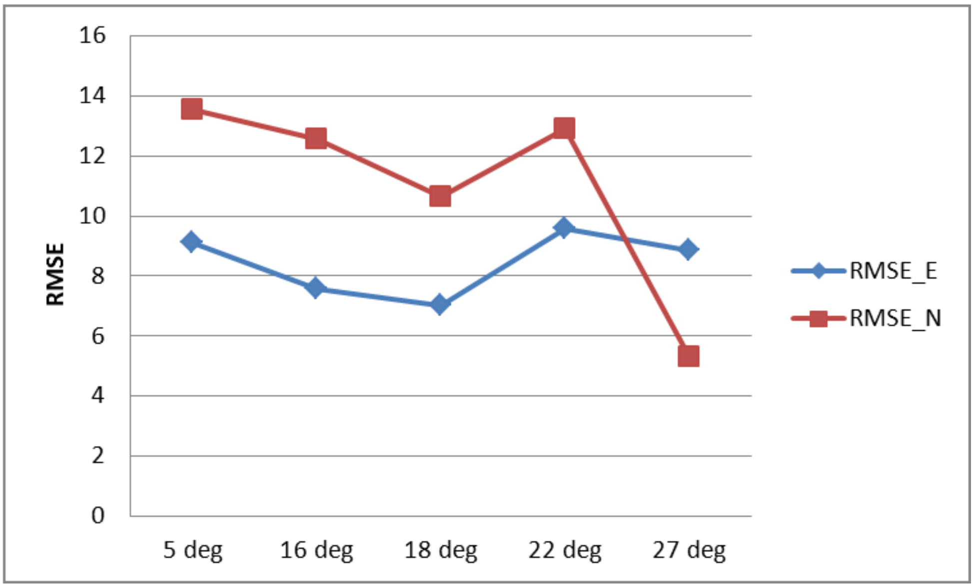

Figure 11: After systematic error elimination, relative accuracy (MS)

The results of the absolute and relative accuracy for PAN and PS, before and after systematic error elimination are presented on figures 12-13:

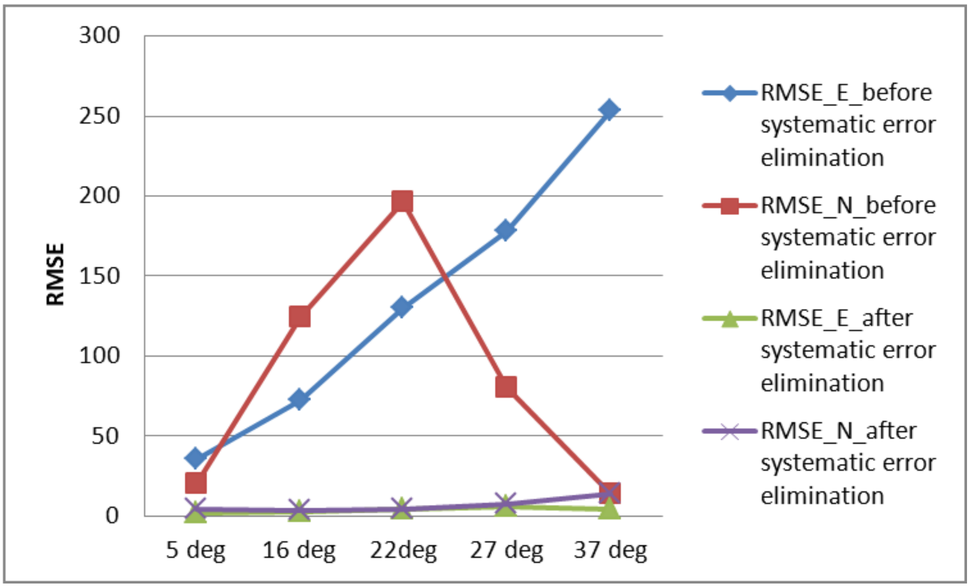

Figure 12: Before and after systematic error elimination, relative accuracy (PAN, PS)

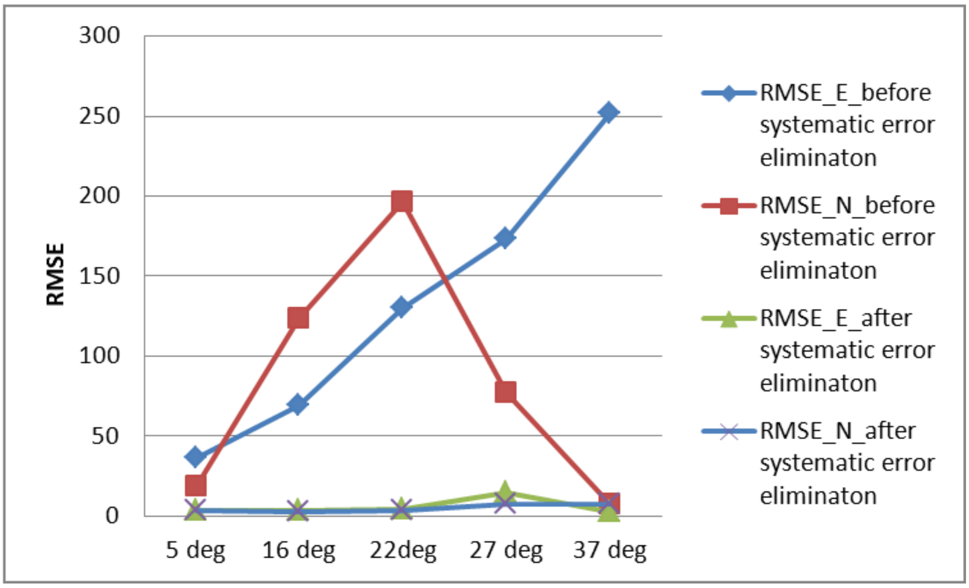

Figure 13: Before and after systematic error elimination, absolute accuracy (PAN, PS)

5.3. THEOS Orthoimage generated from level 1A using Keystone Spacemetric

Spacemetric performed modelling and orthorectification of the three PAN and MS 1A THEOS images using the Keystone matching techniques for GCP and ICP choice and measurement. The following data was used as auxiliary information:

- ADS40 aerial orthoimage (Panchromatic at 0.5 m resolution)
- DEM derived from the ADS40 imagery at 2 m grid interval and RMSEz of 0.6m
- Landsat7 ETM+ Pan orthorectified scene from GLCF (15 m resolution)
- SRTM DEM, CGIAR version 4 (90 m grid interval)

Spacemetric provided the JRC with their final THEOS orthoimages, therefore we could perform the external quality control using our set of ICPs (see chapter 2.4), and compare the both results (see chapter 5.5).

The results of the absolute and relative accuracy for THEOS PAN and MS orthoimage are presented in figures 14, 15 and 16.

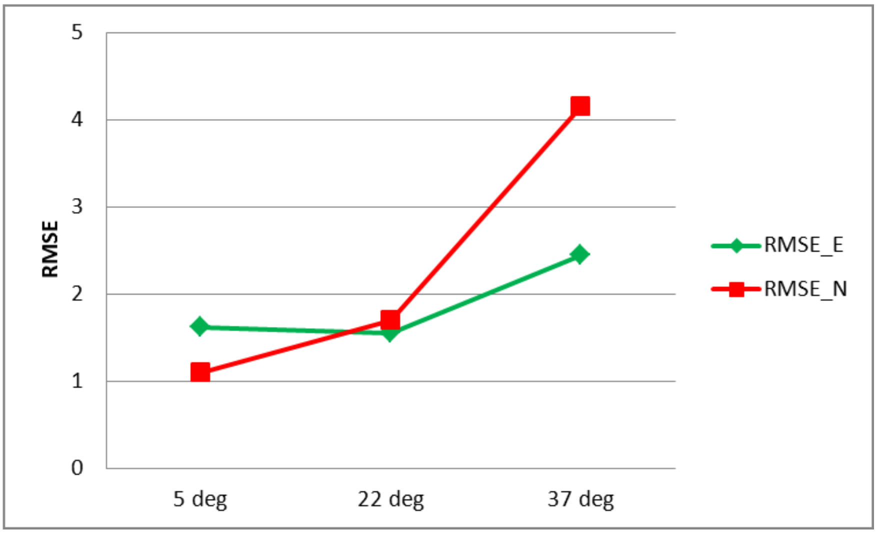

Figure 14: Absolute accuracy on orthos produced by Spacemetric (PAN)

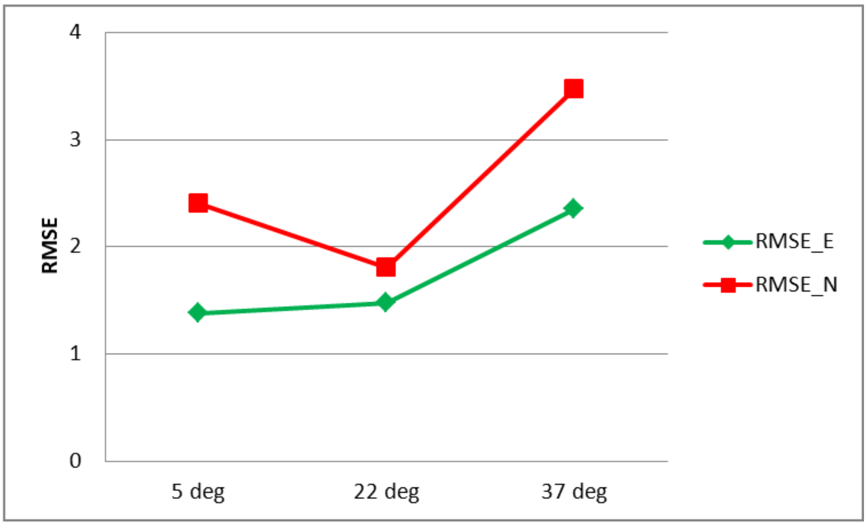

Figure 15: Relative accuracy on orthos produced by Spacemetric (PAN)

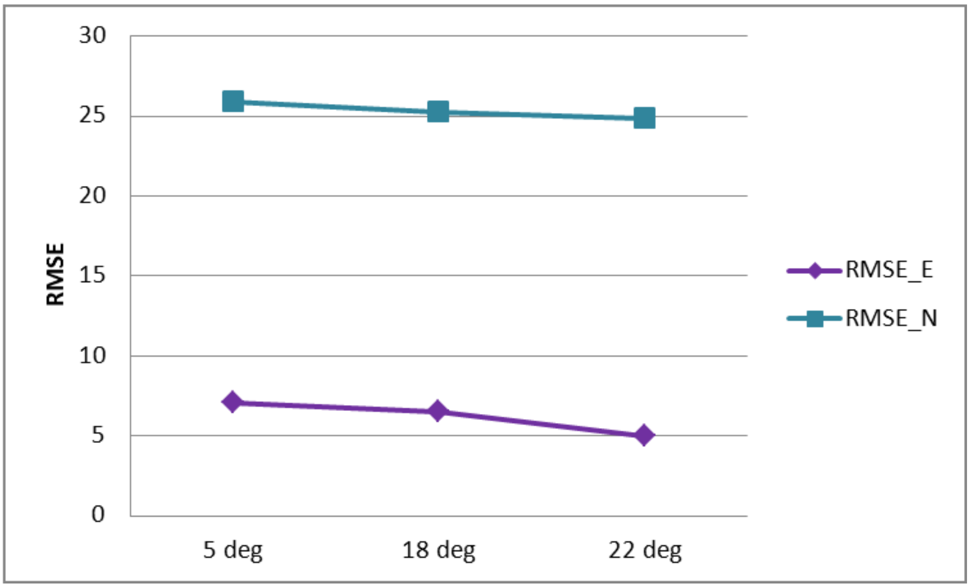

Figure 16: Before systematic error elimination, relative accuracy on orthos produced by Spacemetric (MS)

The results of the absolute and relative accuracy for THEos MS orthoimagery after systematic error elimination is presented in figure 17.

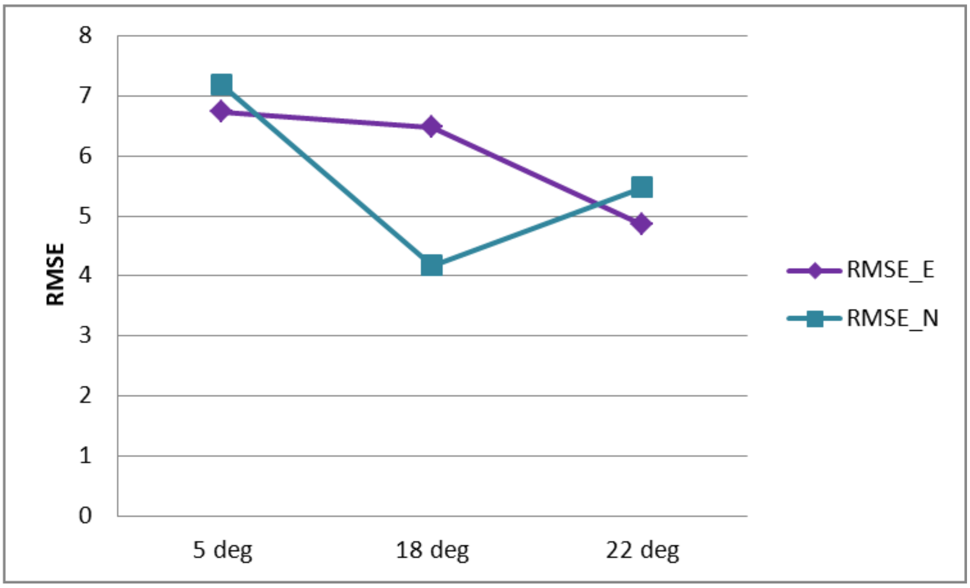

Figure 17: After systematic error elimination, relative accuracy on THEOS orthoimages produced by Spacemetric (MS)

5.4. JRC and Spacemetric Relative Accuracy Comparison of THEOS Orthoimages Generated from 1A by Keystone Spacemetric

Spacemetric performed modelling and orthorectification of the three PAN and MS 1A THEOS images using the Keystone matching techniques for GCP and ICP choice and measurement. As validation data for PAN THEOS orthoimage , Spacemetric used a set of 9 ICPs extracted from PAN ADS40 aerial orthoimage (0.5 m resolution) by using automatic matching in Keystone. Horizontal and vertical coordinates were acquired respectively from:

- ADS40 aerial orthoimage (Panchromatic at 0.5 m resolution)
- DEM derived from the ADS40 imagery at 2 m grid interval and RMSEz of 0.6m.

As validation data for MS THEOS orthoimage , Spacemetric used a set of 9 ICPs extracted from Landsat7 ETM+ Pan orthorectified scene from GLCF (15 m resolution) by using automatic matching in Keystone. Horizontal and vertical coordinates were acquired respectively from:

- Landsat7 ETM+ Pan orthorectified scene from GLCF (15 m resolution)
- SRTM DEM, CGIAR version 4 (90 m grid interval).

Their very promising results (presented in tables 30 and 31, and on figures 18 and 19) are relative values to the reference orthoimages, i.e. ortho ADS40 or Landsat7 for PAN and MS respectively. The same figures (i.e. 18 and 19) show the results of the external quality controls performed both by JRC and by Spacemetric).

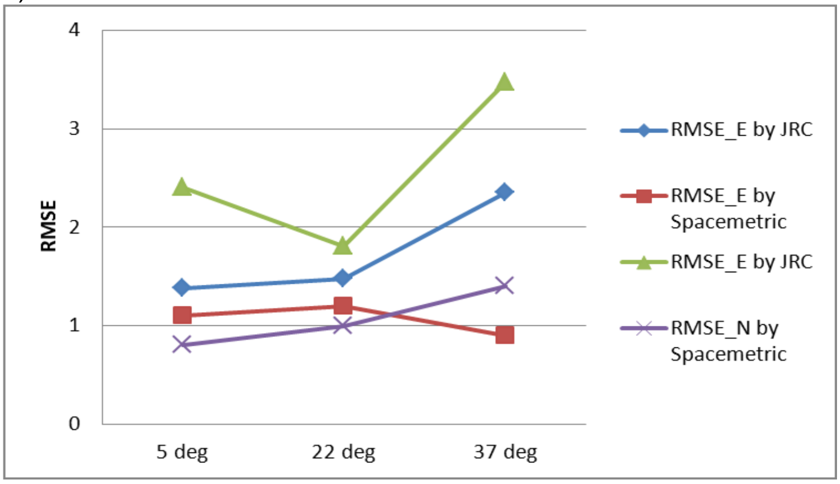

Figure 18: Relative Accuracy by JRC and by Spacemetric (PAN)

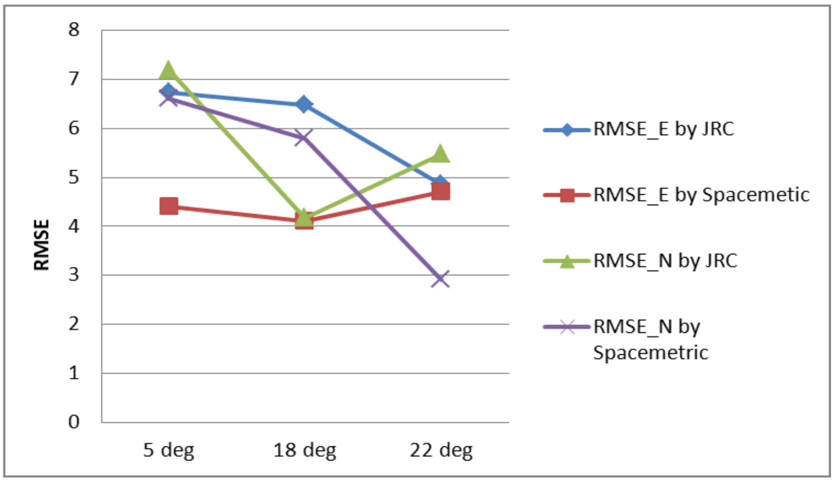

Figure 19: Relative Accuracy by JRC and by Spacemetric (MS)

6. Summary of Key Issues

This report presents the geometric quality results recorded for few samples of the THEOS 2A and orthorectified 1A images acquired over the JRC Maussane Terrestrial Test Site.

The key issues identified during the geometric quality testing based on the limited THEOS sample images that were made available to us are summarised below:

1. The 1-D RMS errors measured on the THEOS 2A PAN product or THEOS 1A PAN orthorectified image are sensitive to the overall off-nadir angle and increase with increasing off-nadir angle, especially when the angle exceeds 22 degrees;

2. The 1-D RMS errors measured on the THEOS 2A MS product or THEOS 1A MS orthorectified image are not sensitive to the overall off-nadir angle;

3. The average absolute 1-D RMSE for the THEOS 2A PAN product are 5m and 6m for Northing and Easting direction respectively, provided systematic error elimination (otherwise the values are as big as 87m and 137m).

4. The average absolute 1-D RMSE for the THEOS 2A MS product are 11.5m and 8.6m for Northing and Easting direction respectively, provided a systematic error elimination (otherwise the values are as big as 119m and 90m).

5. **The average absolute 1-D RMSE for the orthorectified THEOS 1A PAN product are 2m and 2m for Northing and Easting direction respectively respectively (1 pixel accuracy), provided a DTM with 0.6m vertical accuracy and 9 GCPs characterised by max RMSEx,y of 0.90m are used, and a dedicated rigorous model is applied**.

6. **The average absolute 1-D RMSE for the orthorectified THEOS 1A MS product can reach 6.8m and 6.8m for Northing and Easting direction respectively, provided systematic error elimination (that is a consequence of auxiliary data used, being – in our case – ground control points collected from orthorectified Landsat7 ETM PAN data of 15m accuracy and SRTM DEM CGIAR version 4 of 90 m grid interval).**

7. The average relative (to Landsat 15-m orthoimage) 1-D RMSE for the orthorectified THEOS 1A MS product are 5m and 4m for Northing and Easting direction respectively.

7. References

- THEOS User Guide (version 2, 21.09.2009)
- http://www.gisdevelopment.net/tutorials/tuman002c.htm
- http://www.a-a-r-s.org/acrs/proceeding/ACRS2006/Papers/O-1_O2.pdf
- http://www.gisdevelopment.net/technology/rs/mwf09_THEOS.htm

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Abstract
This report summarizes the initial outcome of the geometric quality testing of the panchromatic, pan-sharpening and multispectral THEOS images (level 1A and 2A) acquired over the JRC Maussane Test Site for the Common Agriculture Policy (CAP) Control with Remote Sensing (CwRS) Programme.
Based on the limited K2, THEOS and DMCII sample images that were made available to us the THEOS PAN orthoimage can reach 2m accuracy provided that a dedicated rigorous model based on at least 9 well-defined, well-distributed ground control points (GCPs) of high accuracy (i.e. $RMSE_{x,y} < 0.90m$) is applied; while the orthorectified THEOS 1B MS product accuracy can reach 6.8m, provided that a dedicated rigorous model based on at least 9 well-distributed GCPs of appropriate accuracy is applied.

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