AUTOMATIC TOPOGRAPHIC FEATURES EXTRACTION FROM PLÉIADES HR AND ORBVIEW-5 SIMULATED DATA

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ABSTRACT:

In the next future new high-resolution (HR) multispectral, hyperspectral and radar satellite will be launched. In particular, from 2007 it is expected to be launched the first European satellite constellation with sub-meter resolution ORFEO (*Optical and Radar Federated Earth Observation*), composed of two French optical satellites (Pléiades HR) with 0.70 m resolution and four Italian X-band SAR satellites (COSMO-SkyMed). In the same year it is planned to be operative the first commercial ultra-high-resolution (UHR) satellite, OrbView-5, being able to collect imagery with 0.41 m resolution. This paper presents a first test of automatic topographic feature extraction – by means of the Automatic Ground control points Extraction (AGE) technique developed in the last years – for the future Pléiades HR and the OrbView-5 panchromatic data. Simulated images have been obtained both from 1:1,000 scale aerial othophotos and from a real QuickBird survey. Results showed that for the Pléiades HR satellites it is expected a metric precision of the extracted GCPs between 1.12 m and 2.07 m, while for the OrbView-5 it is expected a precision between 0.60 m and 1.10 m. These data are suitable for obtaining orthoimages with an RMSE better than 2.5 m for Pléiades HR and better than 1.5 m for OrbView-5, without any knowledge of the sensor model, of the satellite orientation and without any use of measured GCPs. Moreover, Plèiades HR results may be extended to the next generation Israeli EROS-B satellites, which will have a synchronous pushbroom high-resolution imaging camera with expected resolution of between 0.82 m and 0.70 m.

1. INTRODUCTION

In the next future new optical and radar high-resolution (HR) satellite systems will be launched, characterized by higher observation capabilities and being able of monitoring the environment in a more efficient way.

Concerning the optical sensors, many Countries are developing constellations of satellites for the Earth Observation (EO) with metric or sub-metric geometric resolution. Some examples are the Indian satellite CartoSat-2, with 1-meter Ground Sampling Distance (GSD), whose launch is expected at the end of 2005 (Indian Space Research Organisation, 2005). The Israeli EROS-B, evolution of the actual EROS-A1, is expected to be operational in early 2006 and will be characterized by a pixel size between 0.82 m and 0.70 m in panchromatic mode (ImageSat International, 2005). With similar geometric resolution (0.70 m GSD in panchromatic mode) it is planned for 2007 the French constellation Pléiades HR (Baudouin *et al.*, 2001; CNES, 2005). Again, for 2007 it is planned the development of the U.S. satellite OrbView-5, which is accredited to be the first commercial satellite with less than half-meter resolution (Orbimage, 2005).

On the front of the development of hyperspectral sensors, in 2000 NASA has begun the experimentation of Hyperion, a 220 band imaging sensor with 30-meters GSD (Gianinetto and Lechi, 2004; NASA, 2005). In the same direction is moving the Australian Space Agency, whose satellite ARIES-1, mounting a 105 contiguous spectral band with 30-meter spatial resolution sensor, is expected to become operational in the course of the 2005 and the Italian HypSEO (HyperSpectral Earth Observer) planned to be launched in 2007 (Sabatini *et al.* 2001; Zoffoli *et al.*, 2001; Morea and Sabatini, 2003).

For what concerns the development of the radar sensors, the tendency for the next decade will be that to design constellations of small satellites, characterized by high geometric resolution and short revisiting time. The first Italian civil Remote Sensing (RS) program, COSMO-SkyMed, composed of four X-band Synthetic Aperture Radar (SAR) satellites, has to become operational from the end of 2005 (Boccardo *et al.*, 2003; Italian Space Agency, 2005). It is in final stage the development of the Japanese Advanced Land Observing Satellite (ALOS) system, an L-band SAR satellite with stereoscopic HR capacity (Keydel, 2005; Earth Observation Research and application Center Japan Aerospace Exploration Agency, 2005), while the SAR-Lupe system, awaited between 2005 and 2008, is planned to be composed by a constellation of five X-band satellites disposed on three different orbital planes (Keydel, 2005).

2. FUTURE SUB-METRIC SATELLITES : PLÉIADES HR AND ORBVIEW-5

Pleaides is the name the French constellation composed of two HR satellites planned for launch in 2007. Together with the four Italian COSMO-SkyMed X-SAR satellites, they will form the first European sub-meter constellation known as ORFEO (*Optical and Radar Federated Earth Observation*). The ORFEO constellation will be the most advanced system of the European Union (EU) both for military and civil observations. Regarding the civil applications, ORFEO has been especially designed for the environmental monitoring, for the management of great risks and for the civil protection support (Baudoin, 2004; CNES, 2005, Italian Space Agency, 2005).

The Pléiades satellites will be placed on a sun-synchronous orbit at an altitude of 694 km, with a descending node at 10.15 and an orbital cycle of 26 days. The optical sensor, Pléiades HR, will have a 0.70 m GSD for the panchromatic mode and a 2.80 m GSD for the four-band multispectral mode. With a roll orientation capability of 30° with respect to the track, when fully operational, world access will be achieved in 4 days, with the ability of simultaneous stereoscopic or tri-stereoscopic in-track acquisitions (CNES, 2005).

On September 2004 Orbimage announced that the company contract with the National Geospatial-Intelligence Agency (NGA) for the distribution of their OrbView-3 HR satellite imagery until 2008, will provide Orbimage the capital for the development of next-generation ultra-high-resolution (UHR) imaging satellite OrbView-5. The OrbView-5 satellite actually is accredited to be the first civil observing satellite with less than half-meter resolution. In a sun-synchronous orbit at 660 km above the Earth, it will be able to collect imagery with 0.41 m GSD in the panchromatic mode and with 1.64 m GSD in the multispectral mode (Orbimage, 2005).

3. AUTOMATIC GEOCODING OF SATELLITE DATA

The high geometric detail of the actual (QuickBird, Ikonos, Eros-A1, SPOT-5, OrbView-3) and future satellites (Pléiades HR, OrbView-5, Eros-B) is introducing the possibility of using them to derive and to upgrade large and medium scale maps. In particular, the goal which sounds today achievable is to upgrade topographic maps up to 1: 10,000 scale. Today higher scale maps are not reasonable derivable, because of the high planimetric accuracy needed and even if the actual pixel size of some spaceborne sensors (like QuickBird) is compatible with higher scale maps, the limiting factor for the map production and upgrade process is the image orthorectification step.

The geometric correction of HR satellite images can be carried out through parametric (rigorous) models based on the photogrammetric collinearity equations, or, more frequently, using generic non-parametric models that relates image to terrain coordinates. Traditional approaches to image geocoding relies on the measurement of a sufficient number of GCPs in both the ground and the image reference systems which are used to compute a geometric transformation between the two reference systems.

The most frequently used non-parametric method is based on the 3D Rational Function Model (RFM), which determines a relationship between image coordinates (x, y) and 3D object coordinates (E, N, Z) through polynomial ratios (Dowman and Tao, 2002; Boccardo *et al.*, 2003; Zhizhong Xu, 2004; Toutin., 2004). The most critical element of the RFM technique is the strong dependence of the solution from the number and the distribution of GCPs. Bad configuration, such as small number of GCPs not regularly distributed, can easily lead to heavy distortions (asymptotes) over the corrected images. Best results, on the contrary, are obtained with a large number of GCPs with a regular planimetric and altimetric distribution. Unfortunately, the GCP collimation is a widely time-consuming operation and not always a simple task.
Recently it has been proposed a non conventional orthorectification processing chain based on the Automatic Ground control points Extraction (AGE) technique (Scaioni and Gianinetto, 2003), a Neural Network Multi Layer Perceptron (NNMLP) GCPs regularization and a final self-computed RFM (Gianinetto *et al.*, 2004). The core of the processing is the AGE procedure, used to automatically extract GCPs from an image pair (Figure 1). The basic idea is to use as master source data an already rectified image (for example an aerial orthophoto) to collect, in an automatic way, a very large number of topographic features in an un-rectified satellite image, whose cartographic coordinates are derived from the master dataset. These features are then used as GCPs in the orthorectification process.

AGE is based on an image-to-image registration approach derived from the digital photogrammetry (Heipke, 1997) that use the Förstner interest operator (Förstner, 1982; Förstner 1985), a sub-pixel least squares matching and a robust outlier estimator based on the least median squares for the automatic collecting and measurement of ground control points (GCPs) extracted from image pairs. Figure 1 show the flowchart of the AGE algorithm. An exhaustive description of the AGE technique can be found in Chirici *et al.* (2004) and in Gianinetto *et al.* (2004).

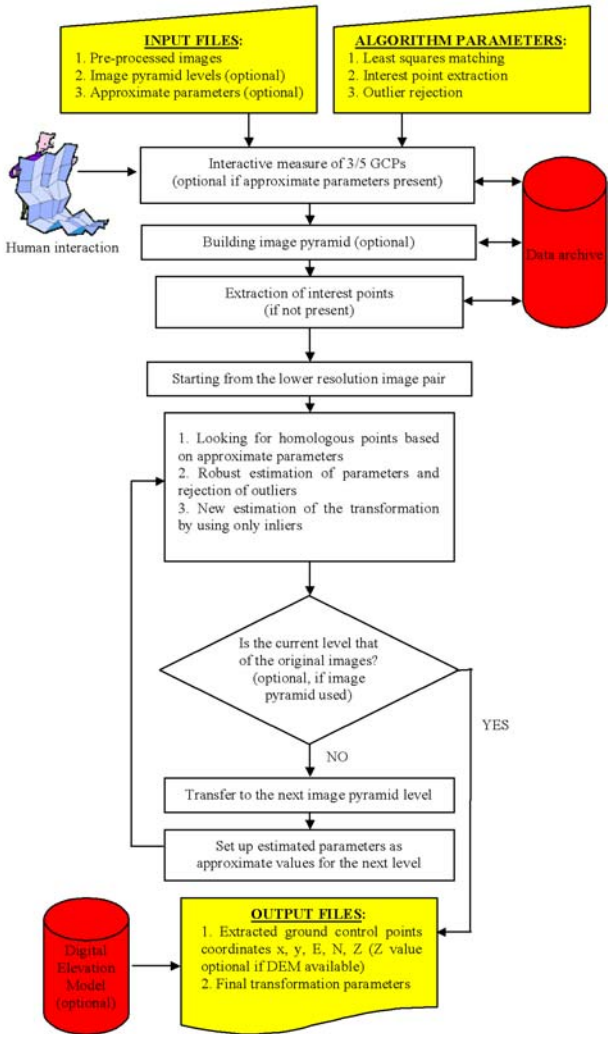


Figure 1. Flowchart of the AGE algorithm

4. DATA SIMULATION

Simulations of Pléiades HR and OrbView-5 panchromatic imagery have been made for a test site in the city if Venice (Italy) at the Arsenale di Venezia (Venice arsenal) location. The

Arsenale di Venezia may be considered the first factory of the history and constitutes a very wide part of the insular city of Venice. It was the heart of the naval Venetian industry from the XII Century and, thanks to the ships here built, Venice succeeded to oppose the turkishes in the Aegean Sea and to conquer the courses of the northern Europe.

For both the Pléiades HR and OrbView-5 tests, nadir synthetic data have been generated from 1:1,000 scale map aerial orthophotos (Figure 2), and, for the Pléiades HR, an off-nadir simulation with 8°.63 in-track view angle and 9°.20 cross-track view angle has been also made from a real QuickBird survey (Figure 3).

The aerial orthophotos have been first resampled from the original resolution (0.10 m GSD) to the Pléiades HR (0.70 m GSD) and OrbView-5 (0.41 m GSD) planned resolution. Then, the resampled data have been geometrically deformed using a second order polynomial function with nearest neighbor (NN) interpolation to simulate a geographic displacement. Finally, blurring was added to the images using a low pass filter with 3x3 pixel kernel and a radiometric equalization was applied on a mixed urban/water sample to simulate the effect of the integration time typical of digital sensors.

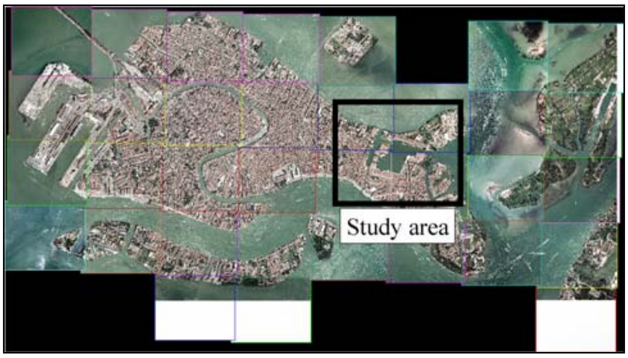


Figure 2. Aerial orthophoto mosaic of Venice (1:1,000 scale) with highlighted the study area of the “Arsenale di Venezia”

Figure 3. QuickBird imagery of Venice (0.63 m GSD) taken on 16 May 2002

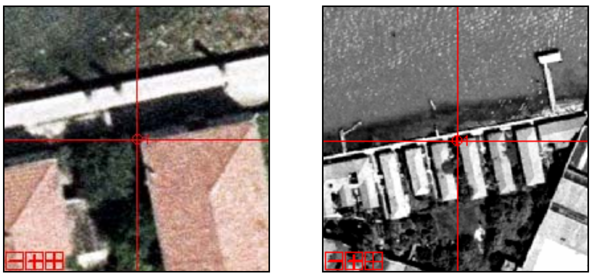
5. RESULTS

5.1 Pléiades HR simulations

The nadir Pléiades HR imagery simulated from the aerial orthophotos (Figure 4) has been processed with the AGE technique, using as master image the same orthophotos resampled to match the Pléiades HR resolution. 172 GCPs with high correlation values (ρ=0.80) have been automatically extracted around the Arsenale di Venezia. Figure 4 show the Pléiades HR simulation obtained from the aerial orthophotos with superimposed the GCPs identified by the matching algorithm and Figure 5 show an example of GCP automatically extracted both on the orthophoto and on the simulated Plèiades HR at their original resolution.

Using the QuickBird data, an off-nadir Pléiades HR image was simulated with 8°.63 in-track view angle and 9°.20 cross-track view angle. In this second test, 173 GCPs with 0.80 correlation value have been automatically extracted and geocoded. Figure 6 show the Pléiades HR simulation obtained from the QuickBird data with superimposed the GCPs identified by the AGE algorithm and Figure 7 show an example of GCP automatically extracted both on the orthophoto and on the simulated Plèiades HR at their original resolution.

Figure 4. Nadir-looking Pléiades HR simulation generated from aerial orthophotos with superimposed the GCPs identified by the AGE algorithm



(a) (b)

Figure 5. Pléiades HR simulation from orthophotos. Example of GCP identification: (a) orthophoto, (b) Nadir-looking Pléiades HR

To evaluate the geometric accuracy of the derived GCPs, a set of 27 Check Points (CPs) have been randomly selected and manually measured. For the simulation obtained from the orthophotos, an RMSE of 2.07 m (2.96 pixel) has been obtained, with a maximum RMS of 5.15 m (7.35 pixel) for CP nr.118, a minimum RMS of 0.18 m (0.25 pixel) for CP nr.46, a mean RMS value of 1.67 m (2.39 pixel) and a standard deviation of 1.18 m (1.69 pixel).

Better results have been assessed for the simulation from the real QuickBird data, with an RMSE of 1.12 m (1.59 pixel), a maximum RMS of 3.05 m (4.35 pixel) for CP nr.89, a minimum RMS of 0.20 m (0.28 pixel) for CP nr.79, a mean RMS value of 0.91 m (1.30 pixel) and a standard deviation of 0.62 m (0.89 pixel). Tables 2 and 4 show results.

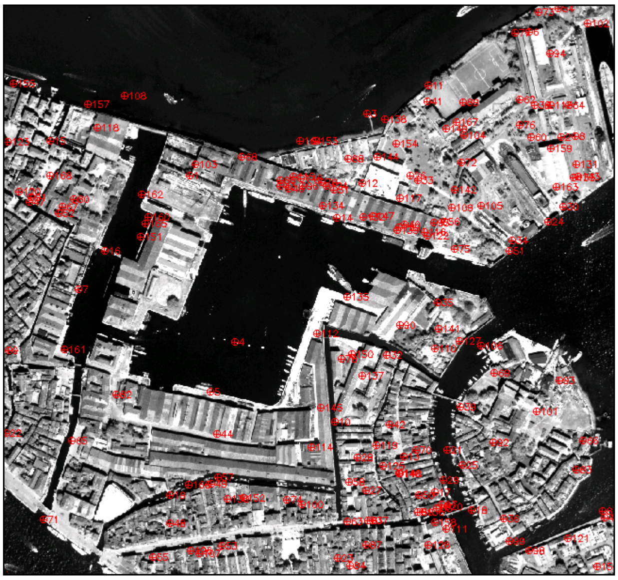
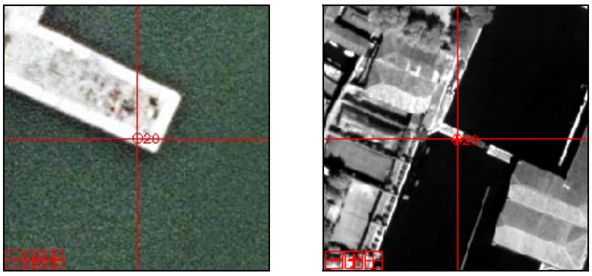


Figure 6. Off-nadir Pléiades HR simulation generated from QuickBird data with superimposed the GCPs identified by the AGE algorithm



(a) (b)

Figure 7. Pléiades HR simulation from QuickBird. Example of GCP identification: (a) orthophoto, (b) Off-nadir Pléiades HR

	Nadir-looking Simulation from aerial orthophotos		Off-nadir Simulation from QuickBird data	
CP	**Pixel**	**Meters**	**Pixel**	**Meters**
2	1.84	1.29	0.87	0.61
12	2.25	1.58	0.36	0.25
13	3.91	2.74	0.72	0.50
17	2.08	1.46	1.27	0.89
25	0.79	0.55	0.83	0.58
34	3.05	2.14	1.30	0.91
38	0.75	0.53	1.61	1.13
41	1.41	0.99	0.63	0.44
46	0.25	0.18	0.99	0.69
51	2.68	1.88	1.08	0.76
59	0.68	0.48	0.44	0.31
65	2.29	1.60	0.79	0.55
71	1.58	1.11	0.98	0.69
77	1.79	1.25	0.80	0.56
79	3.77	2.64	0.28	0.20
81	0.71	0.50	2.60	1.82
83	2.99	2.09	0.81	0.57
85	2.16	1.51	2.25	1.58
89	0.99	0.69	4.35	3.05
94	0.79	0.55	0.90	0.63
107	5.73	4.01	2.60	1.82
118	7.35	5.15	0.72	0.50
125	4.83	3.38	1.39	0.97
132	1.12	0.78	2.24	1.57
143	3.02	2.11	0.78	0.55
148	3.86	2.70	1.93	1.35
163	1.74	1.22	1.48	1.04

Table 2. Pléiades HR simulations. Residual errors (RMS) computed for 27 check points

5.2 Orbview-5 simulation

Due to the very high-resolution expected for its panchromatic band, only a nadir-looking OrbView-5 data has been simulated from the aerial orthophotos and tested with AGE (Figure 8). The AGE algorithm identified 275 GCPs with higher correleation values than those extracted for the Pléiades HR simulation (ρ=0.85). Figure 8 show the OrbView-5 simulation obtained from the orthophotos with superimposed the GCPs extracted by AGE and and Figure 9 show an example of GCP automatically extracted both on the orthophotos and on the simulated OrbView-5 at their original resolution.

Again, to evaluate the geometric accuracy of the derived GCPs, a set of 21 CPs have been randomly selected and manually measured. For this test it was obtained an RMSE of 1.10 m (2.76 pixel), with a maximum RMS of 2.26 m (5.66 pixel) for CP nr.229, a minimum RMS of 0.00 m for CP nr.119, a mean RMS value of 0.83 m (2.07 pixel) and a standard deviation of 0.70 m (1.75 pixel). Tables 3 and 4 show results.

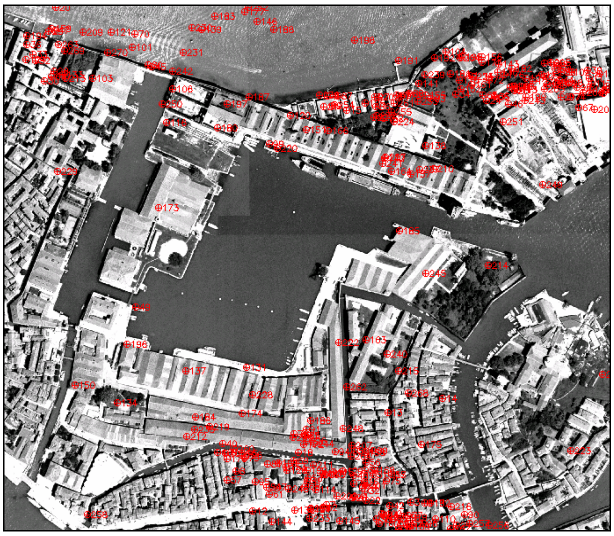
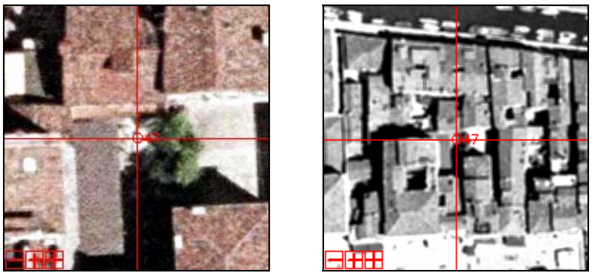


Figure 8. Nair-looking Orbview-5 simulation generated from aerial orthophotos with superimposed the GCPs identified by the AGE algorithm



(a) (b)

Figure 9. Orbview-5 simulation from aerial orthophotos. Example of GCP identification: (a) orthophoto, (b) OrbView-5

CP	Pixel	Meters	CP	Pixel	Meters
10	0.78	0.31	**111**	0.51	0.21
21	0.73	0.29	**119**	0.00	0.00
28	0.85	0.34	**152**	1.30	0.52
41	1.00	0.40	**159**	2.28	0.91
50	3.94	1.58	**200**	0.61	0.24
60	5.45	2.18	**208**	1.75	0.70
70	0.64	0.26	**214**	0.00	0.00
79	2.71	1.08	**225**	1.57	0.63
90	4.40	1.76	**229**	5.66	2.26
99	4.25	1.70	**253**	3.04	1.22
108	2.10	0.84	**111**	0.51	0.21

Table 3. Orbview-5 simulation from aerial orthophotos. Residual errors (RMS) computed for 21 check points

6. CONCLUSIONS

The simulations of nadir-looking images carried on for the Pléiades HR and for the OrbView-5 satellites, using as source data 1:1,000 scale orthophotos, showed that the AGE technique was able to identify topographic features with a density of 177 GCPs/km^2 and 299 GCPs/km^2 respectively and with an RMSE<3 image pixel (respectively 2.07 m for the Pléiades HR and 1.10 m for the OrbView-5 data).

The off-nadir Pléiades HR simulation based on real QuickBird data showed an increment in the GCPs precision (RMSE=1.12 m, 1.59 pixel) with the same point density as assessed for the simulation from orthophotos (178 GCPs/km^2). This probably means that real data will be less affected by geometric distortions than those simulated in the presented tests.

Based on results, for the Plèiades HR it is reasonable to expect a precision of automatic topographic features extraction between 1.12 m and 2.07, while for the OrbView-5 imagery a precision between 0.60 m (corresponding to 1.59 image pixel as assessed for the Pléiades HR simulation from real satellite data) and 1.10 m. Summary results as reported in Table 4.

These data are suitable for obtaining orthoimages with an RMSE better than 2.5 m for Pléiades HR and better than 1.5 m for OrbView-5, without any knowledge of the sensor model, of the satellite orientation and without any use of measured GCPs. Moreover, Plèiades HR results may be extended to the next generation Israeli EROS-B satellites, which will have a synchronous pushbroom high-resolution imaging camera with expected resolution of between 0.82 m and 0.70 m.

Better GCPs geometric configurations, with topographic features extracted in a more uniform way on the whole image, can be achieved by relaxing the correlation request between the master source data (orthophoto) and the satellite un-rectified image. Extensive testing on QuickBird, Ikonos and Spot-5 data actually in progress by the author are showing that, using a correlation level between 0.70 and 0.75 and restricting the feature extraction only to the most contrasted topographic elements, it is possible to extract a large number of GCPs (about a thousand for every scene) with a density between 3.5 and 4.4 GCPs/km^2, a good geometrical configuration (without gaps) and with a metric precision better than 3 image pixel.

	Narid-looking Pléiades HR simulation		**Off-nadir Pléiades HR simulation**		**Nadir-looking OrbView-5 simulation**	
	Pixel	**Meters**	**Pixel**	**Meters**	**Pixel**	**Meters**
Max RMS	7.35	5.15	4.35	3.05	4.35	3.05
Min RMS	0.25	0.18	0.28	0.20	0.28	0.20
Mean RMS	2.39	1.67	1.30	0.91	1.30	0.91
Std. Dev. RMS	1.69	1.18	0.89	0.62	0.89	0.62
RMSE	***2.96***	***2.07***	***1.59***	***1.12***	***1.59***	***1.12***

Table 4. Accuracy summary results

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