



## Assessing geometric accuracy of the orthorectification process from GeoEye-1 and WorldView-2 panchromatic images

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### ABSTRACT

GeoEye-1 and WorldView-2 are the commercial very high resolution (VHR) satellites more innovative, unexplored and presenting the highest available resolutions nowadays. The attainable geopositioning accuracies from GeoEye-1 and WorldView-2 single panchromatic images, both along the sensor orientation and orthorectification phases, are analyzed at the same study area and by using exactly the same ancillary data. The accuracy assessment was carried out depending on the following factors: (i) type of input satellite image (GeoEye-1 Geo, WorldView-2 Ortho Ready Standard and WorldView-2 Basic), (ii) sensor orientation model used (rigorous and based on rational function), (iii) number of well-distributed ground control points (GCPs) used in the triangulation process, (iv) off-nadir viewing angle, and finally (v) vertical accuracy of the DEM employed to conduct the orthorectification process.

Regardless of satellite or product, the best horizontal geopositioning accuracies were always attained by using third order 3D rational functions with vendor's rational polynomial coefficients data refined by a zero order polynomial adjustment (RPC0). Focusing on WorldView-2 products, worse accuracies were yielded from Basic images than from Ortho Ready Standard level ones.

As a general rule, and for attaining sub-pixel planimetric accuracies for the orthorectified GeoEye-1 Geo and WorldView-2 Ortho Ready Standard images and using RPC0 model with 7 GCPs, users should avoid off-nadir angles higher than 20° and use a very accurate DEM.

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### 1. Introduction

Orthorectification of satellite data is one of the most important pre-processing steps for mapping applications, for identifying a broader range of land or urban features (i.e., image classification) and for adding georeferenced image data into Geographic Information Systems. In this way, the recent advent of the first very high resolution (VHR) satellites, capable of capturing panchromatic (PAN) imagery of the land surface with Ground Sample Distance (GSD) even lower than 1 m, marks a new era in the field of remote sensing. Although many VHR satellites have been successfully launched during the last decade, nowadays the couple of commercial VHR satellites more innovative and unexplored are GeoEye-1 (GeoEye, Inc.) and WorldView-2 (DigitalGlobe, Inc.), launched in September 2008 and October 2009 respectively. Many studies have been carried out in applications of these new breed of VHR remote sensing images (e.g., Dennison et al., 2010; Ozdemir and Karnieli, 2011). Currently, GeoEye-1 is the commercial satellite with the highest geometric resolution, with 0.41 m GSD at nadir

in PAN imagery and 1.65 m GSD at nadir in multispectral (MS) imagery. On the other hand, WorldView-2 has the ability to collect PAN and MS images (the first VHR commercially available 8-band MS satellite) with pixel size of 0.46 m and 1.84 m at nadir respectively. However, image products from GeoEye-1 and WorldView-2 have to be down-sampled to 0.5 m and 2 m in PAN and MS respectively for commercial sales, as a requirement levied by the U.S. Government.

Users can produce their own highly accurate orthorectified images by utilizing commercial off-the-shelf software and ancillary data such as digital elevation models (DEMs) and ground control points (GCPs) through VHR satellite imagery available as (i) Basic images (very close to the original images) or (ii) images projected to a plane with constant height (map-projected level). DigitalGlobe's VHR satellites are available in both, Basic product and Ortho Ready Standard Level-2A (ORS2A) images (DigitalGlobe, 2010), whereas GeoEye's ones (GeoEye, 2009) only are attainable as map-projected level (Geo images). The first step for carried out the orthorectified process would be the triangulation or sensor orientation whereas the final product would be generated by removing the distorting affects of the terrain relief using a proper DEM. In the last decades, several mathematical models for VHR satellite sensor orientation and 3D geopositioning supported on 3D GCPs have been tested. These models can be categorized into two main groups:

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- (i) 3D rigorous or physical mathematical models which can present accurately the satellite sensor motion in space and the relationship between the satellite image space and the ground space. The use of this group of models depends on the availability and quality of the sensor information and the satellite ephemeris data. Therefore, the form of the rigorous mathematical models may be changed from one sensor to another. DigitalGlobe's Basic images are delivered with a set of metadata files including full information about attitude and ephemeris data, geometric calibration and camera model. Because of these, many physical sensor models only work on this type of images (e.g., Dolloff and Settergren, 2010; Deltisidis and Ioannidis, 2011). In previous studies, rigorous sensor models have proved to be the best option for QuickBird Basic images (e.g., Wolniewicz, 2004; Aguilar et al., 2007). However, they did not work so well on Ikonos or GeoEye-1 Geo images (Wolniewicz, 2004; Aguilar et al., 2008a; Crespi et al., 2010; Aguilar et al., 2012). More recently, Capaldo et al. (2012) compared two different rigorous sensor models with stereo pairs of WorldView-1 (the WorldView-2's older sister satellite) and GeoEye-1. In both cases and after the sensor orientation phase, SISAR software, developed at the Area di Geodesia e Geomatica (Università di Roma, La Sapienza), achieved better results than a 3D physical model included within PCI Geomatica OrthoEngine (PCI Geomatics, Richmond Hill, Ontario, Canada). However, these results were supported in an extremely small number of Independent Check Points (ICPs).
- (ii) Empirical models that can approximate the relationship between the image and the object spaces without any information about the sensor motion in space, the satellite ephemeris or attitude data. In the absence of that complete information, rational functions are introduced by many investigators as mathematical model for image to ground coordinate system transformation in a conventional way (e.g., Tao and Hu, 2001; Grodecki and Dial, 2003; Fraser and Hanley, 2005) or in an innovative way (e.g., Valadan Zoej et al., 2007). The well-known vendor supplied rational polynomial coefficients (RPCs), compensated in image space using a modest number of high accurate 3D GCPs, is the most widely used sensor model for VHR satellite imagery. In this way, using bias-corrected RPCs model and a single GCP, extremely accurate geopositioning results, clearly much better than those attained by using older satellites such as Ikonos or QuickBird, were reported by Fraser and Ravanbakhsh (2009) working on a stereo pair of GeoEye-1.

The main objective of this paper was to compare, exactly in the same conditions, the geopositioning accuracy capabilities of GeoEye-1 (Geo product) and WorldView-2 (ORS2A and Basic products) PAN singles images for generating orthorectified imagery under an operational environment. In this sense, a statistical analysis was performed for studying the following variation sources: (i) type of input VHR PAN satellite image, (ii) sensor orientation model used, (iii) number of well-distributed GCPs used in the triangulation process, (iv) off-nadir viewing angle, and finally (v) accuracy of the DEM employed in the orthorectification process.

## 2. Study site and data set

### 2.1. Study site

The study area is centered on WGS84 geographic coordinates of 37.2109° North and 1.8027° West and it comprises a coastal fringe of Almería (Southern Spain), approximately 11 km long and 775 m wide (Fig. 1). The study area presents a smooth relief, with heights ranging from 0 m to 55 m and a mean value close to 7 m.

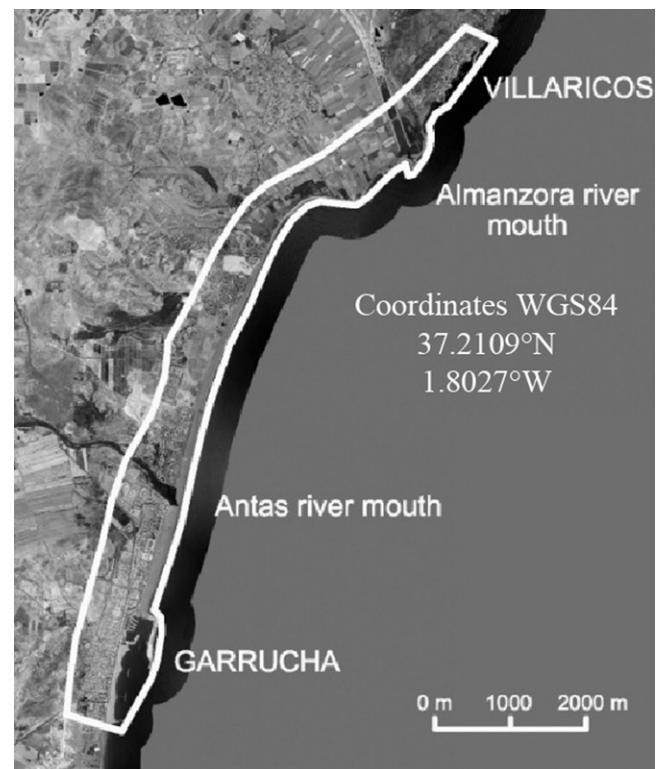


Fig. 1. Location of the study site on the Almería coast, Spain.

### 2.2. Remote sensing data

During 2010 and 2011, eight VHR satellite PAN images covering the study area (three GeoEye-1 Geo images, three WorldView-2 ORS2A and two WorldView-2 Basic images) were acquired. All these images were finally down-sampled to 0.5 m GSD. The characteristics of all of them are shown in Table 1.

#### 2.2.1. GeoEye-1 data

For GeoEye-1, only images projected to a surface with constant height are distributed as Geo images. In fact, GeoEye-1 Geo is the GeoEye's commercial imagery format that presents the least level of corrections, both radiometric and geometric. Geo images are shipped with the sensor camera model in RPCs format and a metadata file. In the last file the most relevant physical parameters of the image are summarized. The Geo product permits skilled users to make orthorectified products using standard commercial software (GeoEye, 2009).

For this work three GeoEye-1 Geo images were acquired. The first one was taken on September 29, 2010, occupying approximately 49 km<sup>2</sup>. On August 27, 2011, a GeoEye-1 GeoStereo product was taken, containing two images which counted on the appropriate stereo geometry to support a wide range of stereo imagery applications such as DEMs creation. In a single image, GeoStereo product is identical to Geo product. Therefore, due to the fact that only single images were going to be computed along this work, we will refer to the GeoStereo and Geo images without any difference from now on. An area of 100 km<sup>2</sup> was ordered for both images taken in August 2011, always including the aforementioned working area.

#### 2.2.2. WorldView-2 data

Through the DigitalGlobe's WorldView-2 (WV-2) satellite images, users can produce their own highly accurate orthorectified products by utilizing commercial off-the-shelf software and ancillary data such as DEMs and GCPs. For this task, the two

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