# Demystification of IKONOS

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IKONOS, the commercial satellite with the highest publicly available resolution, was successfully launched in September 1999. The satellite's sensor can generate 1-m panchromatic and 4-m multiband images with off-nadir viewing up-to-60º in any azimuth for a better revisit rate and stereo capabilities. The high-resolution imagery that IKONOS provides theoretically will have "unlimited" uses in a number of markets (including state and local government) and in various applications such as mapping, agriculture, forestry, and emergency response. Instead of using aerial photos, highly detailed maps of entire countries can be frequently and easily updated using this data. Farmers can monitor the health of their crops and estimate yields with greater accuracy and over shorter intervals. Scientists can look at environmentally sensitive areas and predict trends with greater certainty. Government officials can monitor and plan more enlightened land use policies. City planners can further the development of new housing communities with greater precision and attention. In short, the potential uses for IKONOS imagery are limited only by the imagination.

## What do we expect from IKONOS?

Largely extrapolated on results from similar systems mounted on aircraft or Space Shuttle platforms, IKONOS images have demonstrated a very high potential for national mapping. The principal attraction for the user community is the 1-m pixel, which enables the extraction of objects appearing in most digital mapping products. Users may expect to obtain sub-pixel accuracy (as done with earlier satellites such as SPOT and Landsat), but are these accuracy expectations too high? The off-nadir viewing capability is also an important characteristic of IKONOS since it improves the revisit rate of the same ground area to between two and three days, and also (theoretically) enables the acquisition of stereo images. Users should then apply traditional photogrammetric techniques with these stereo images to extract planimetric and altimetric information, such as a digital elevation model (DEM). Are these stereo data available?

## What do we obtain from IKONOS?

IKONOS data is produced for five different product levels and is available at five different prices. Table 1 shows an example of the basic panchromatic product. Extra charges will be applied for additional special products or services. IKONOS is distributed in 8-bit or 11-bit GeoTiff format with ASCII metadata file (including order parameters and also source image and products file descriptions). A minimum order of US$1000 for North America and US$2000 for International is required. Following confirmation, delivery of orders that are available from archive typically takes several days to just over a week. Delivery of newly collected data typically takes two or more weeks, depending upon order size, weather, accuracy, and both ground control points (GCP) and DEM acquisition time.

**Table 1: Detailed prices for basic panchromatic product from Space Imaging Web Site (http://www.spaceimaging.com/).**

| Product Code | CE90 Accuracy | Price for North America | Price for International |
|---|---|---|---|
| Geo | 50 m | $12 | $29 |
| Reference | 25 m | $29 | $73 |
| Map | 12 m | $39 | $98 |
| Pro | 10 m | $49 | $122 |
| Precision | 4 m | $66 | $149 |

*Note: CE90 is the circular positioning accuracy with a confidence level of 90%. Prices are in US dollars per square kilometer.*

The Geo product, which is the most affordable but offers the lowest positioning accuracy, is not corrected for terrain distortions. It has an accuracy of 50m CE90, which means that any point within the image is within 50 meters horizontally of its true position on the earth's surface 90% of the time. Accuracy becomes worse in mountainous areas if the images are acquired with off-nadir viewing, which is quite common for the IKONOS data. Hence, the product will only meet the geometric requirements of mapping scale at 1:100,000. In addition, stereo images of the Geo products are not distributed to the users, and the raw images (preferred by the photogrammetrist community) are not available.

The Precision product is the most expensive but offers the highest positioning accuracy (4m CE90). To achieve it, the user will have to provide GCPs and a DEM to Space Imaging for generating the ortho-image. Because most of the images are acquired at off-nadir viewing, the accuracy of GCPs should be within one metre accuracy and the DEM should be within 5-m accuracy. Sub-pixel accuracy (which may be obtained with satellites such as SPOT and Landsat) will not be achievable for IKONOS, even for flat terrain.

## What are the problems?

Unlike other commercial satellites, IKONOS does not provide detailed orbital information. In addition, supplying GCPs and a DEM to Space Imaging in order to obtain precise ortho products could represent a delay in using the product. This point also presents a problem for users who are not allowed to release cartographic information of their country. Finally, prices of Precision ortho products are very high in comparison to the Geo product. All these aspects can discourage users to acquire IKONOS data or to use them appropriately. However, is it possible for users to purchase the Geo product (about 5.5 times cheaper than the Precision product) and to geo-correct the data themselves? The short answer is yes. Users will save time, money, they will face less administrative problems associated with releasing GCPs and DEM information, and will appropriately use this new source of data.

## What are the solutions?

Three methods can be used to correct the IKONOS Geo data: The simple polynomial method, the rational polynomial method, and the rigorous (or parametric) model method. The purpose of this article is to apply these three methods to an IKONOS Geo product and to compare the different results.

Often considered outdated, the simple polynomial method is a very uncomplicated method for correcting images. It corrects for basic planimetric distortions of the GCPs. Because this method does not take ground elevation into consideration, it is limited to small and flat areas.

Rational polynomial method is similar to simple polynomial method, except that it involves a ratio of polynomial transformations and it also takes ground elevation into consideration. Therefore, this method can be useful for areas with gentle terrain. Both simple polynomial and rational polynomial methods do not require satellite and sensor information. Since both methods are not rigorously modeled, they require many GCPs and only correct at the GCPs. Distortions between the GCPs are not entirely eliminated.

Rigorous models reflect the physical reality of the complete viewing geometry and correct distortions due to the platform, sensor, Earth, and sometimes the deformations due to the cartographic projection. It then takes into consideration the satellite-sensor information. When compared to simple polynomial and rational polynomial methods, the rigorous model method produces the highest accuracy results with relatively few GCPs.

The fact remains that detailed sensor information for the IKONOS satellite has not yet been released. Despite this, the author of this article (a principal research scientist with the Canada Centre for Remote Sensing (CCRS), Natural Resources Canada), has successfully developed a rigorous IKONOS model using basic information from the metadata and image files. For example, approximate sensor viewing angles can be computed using the nominal collection elevation and the nominal ground resolution in the across and along scan directions. The CCRS model is based upon principles related to orbitography, photogrammetry, geodesy and cartography. It has been successfully applied with only a few GCPs (3-6) to VIR data (Landsat 5 & 7, SPOT, IRS, ASTER, and KOMPSAT), as well as SAR data (ERS, JERS, SIR-C and RADARSAT). Based on good quality GCPs, the accuracy of this model was proven to be within one-third of a pixel for VIR images and one resolution cell for SAR images.

## Experiment

To test the three different methods, an IKONOS Geo product was ordered in April 2000, for the City of Richmond Hill, located north of Toronto, Ontario, Canada. This study area has an elevation range of 180 to 240 meters. The data was delivered within thirty days of order confirmation. The metadata file was processed to compute the satellite parameters for the rigorous model method. Thirty (30) GCPs were collected uniformly on the image and the map coordinates were obtained from 20cm ortho photos and a 2 metre spacing DEM.

To test the geometric correction process, PCI OrthoEngine Satellite Edition V7.0 software (a product that supports all three of the mentioned correction methods) was used. PCI OrthoEngine Satellite Edition V7.0 also supports the reading of different satellite data, GCP collection, geometric modeling, orthorectification, and either manual or automatic mosaicking.

## Results and Analysis

Table 2 shows the root mean square (RMS) and maximum residual of the calculation of the three different methods. Second order polynomial transformations were used for both simple and rational polynomial methods. As seen in Table 2, the rational polynomial method provided the best residuals. However, assessing accuracy with only GCP residuals is misleading and biased because both polynomial methods correct locally at the GCPs.

**Table 2: Comparison of residuals results with 30 GCPs using simple polynomial, rational polynomial, and rigorous model.**

| Correction | RMS Residuals (m) | | Maximum Residuals (m) | |
|---|---|---|---|---|
| Method | X | Y | X | Y |
| Simple Polynomial | 1.0 | 3.2 | 2.4 | 6.2 |
| Rational Polynomial | 0.5 | 0.7 | 1.1 | 1.4 |
| Rigorous Model | 0.8 | 1.1 | 1.9 | 2.8 |

During the acquisition of GCPs, a mistake was made in collecting one of the GCPs. The error was about 20m in the Y-direction. Both simple and rational polynomial methods were unable to detect the erroneous point. Table 3 shows the RMS and the residuals of the erroneous point. The Y-residual of the erroneous point from the rigorous model was four times higher than the RMS residuals and was detected immediately with its error value and direction.

**Table 3: Comparison of residuals results with 30 GCPs including one erroneous point using simple polynomial, rational polynomial, and rigorous model.**

| Correction | RMS Residuals (m) | | Erroneous Point (m) | |
|---|---|---|---|---|
| Method | X | Y | X | Y |
| Simple Polynomial | 1.2 | 3.9 | 2.2 | 6.7 |
| Rational Polynomial | 0.6 | 1.3 | 0.3 | 1.4 |
| Rigorous Model | 1.1 | 3.0 | 2.2 | 11.8 |

Unbiased validation of the positioning accuracy has to be done with independent check points (ICPs), which are not used in the model calculations. Consequently, 23 of the 30 GCPs were changed to ICPs in the second test. Second order was used for the simple polynomial method and first order for the rational polynomial method due to the reduced number of GCPs. Table 4 shows the RMS and maximum errors over the 23 ICPs using the three methods. The errors are smaller with the rigorous method than with both polynomial methods and are also consistent with the residuals of Tables 2 & 3. This shows that the rigorous model is both stable and robust without generating local errors and filters errors. An evaluation of these image parameters computed from the rigorous method (such as the viewing angles) validates the basic assumptions and estimations computed from the metadata file.

**Table 4: Comparison of error results with 23 ICPs and 7 GCPs using simple polynomial, rational polynomial, and rigorous model.**

| **Correction** | **RMS Errors (m)** | | **Maximum Errors (m)** | |
|---|---|---|---|---|
| **Method** | **X** | **Y** | **X** | **Y** |
| Simple Polynomial | 1.7 | 4.1 | 4.1 | 7.5 |
| Rational Polynomial | 2.2 | 5.2 | 5.1 | 10.4 |
| Rigorous Model | 1.3 | 1.3 | 3.0 | 3.0 |

A final evaluation was done by performing a quantitative and qualitative comparison of the ortho-image (Figures 1a, 2a) generated from the rigorous method and a DEM with the 20cm ortho-photos (Figures 1b, 2b). It confirms the previous results over the ICPs that there is no error larger than 4-5 m. Consequently, the accuracy of the rigorous model is within the accuracy of the IKONOS Precision product.

## Conclusions

IKONOS Geo products have an accuracy that is relatively low and inconsistent with their image content quality and their large-scale maps. Precision products can be difficult to generate outside some countries and are otherwise expensive. Consequently, one major drawback of the efficient and appropriate use of the IKONOS products is the inherent impossibility to process and orthorectify the images by the users. Now, users can apply a rigorous model (one that is available in an operational environment) to correct the low-cost Geo products. When accurate ground data is available, users may produce consistent orthoimages which are as precise as the expensive Precision products. Therefore, this technology should promote the acquisition and the use of this new source of data for many applications.

Evaluation is still ongoing at CCRS using other IKONOS images and studying different topographic terrain (mainly high relief) and applications (mapping, forestry, agriculture, etc.) Recent results in mountainous areas are promising for small-scale mapping.

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**Figure 1a: Sample image of IKONOS data of Richmond Hill, Ontario, Canada.**

**Figure 1b: Sample 1:8000 scale aerial photo of Richmond Hill, Ontario, Canada.**

**Figure 2a: Sample IKONOS data of Richmond Hill, Ontario, Canada**

**Figure 2b: Sample 1:8000 scale aerial photo of Richmond Hill, Ontario, Canada**