
# Satellite Photogrammetry

Two (2) Continuing Education Hours
Course #LS1007

Approved Continuing Education for Licensed Professional Engineers & Land Surveyors

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## Course Description:

The Satellite Photogrammetry course satisfies two (2) hours of professional development.

The course is designed as a distance learning course that presents an overview of satellite photogrammetry for licensed land surveyors and professional engineers.

## Objectives:

The primary objective of this course is to enable the student to understand satellite photogrammetry with focus on earth observation satellites that operate in the optical spectrum.

## Grading:

Students must achieve a minimum score of 70% on the online quiz to pass this course. The quiz may be taken as many times as necessary to successful pass and complete the course.

A copy of the quiz questions are attached to last pages of this document.

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Satellite Photogrammetry

# Satellite Photogrammetry

**Overview.** This course provides an overview of satellite photogrammetry and concentrates on earth observation satellites that operate in the optical spectrum. This chapter includes a comparison of high- and medium-resolution commercialimaging satellites; a review of the most common applications for satellite photogrammetry; a review of geo-positioning from satellite images and procedures for creating stereo pairs from satellite imagery; and a review of the top 10 things to consider in buying optical satellite imagery used for satellite photogrammetry, largely extracted from an article, entitled "Buying Optical Satellite Imagery? The Top 10 Things to Consider," by Nick Hubing, published in the May/June 2012 edition (Vol. 9, No. 3) of the *Earth Imaging Journal*, and re-used with permission from the Publisher.

High- and Medium-Resolution Commercial Imaging Satellites. Table 1-1 lists the major characteristics of the most popular high- and medium-resolution commercial imaging satellites. These individual characteristics will be discussed in sections 1-3 through 1-5 below. Temporal resolution is especially tricky to compare because of off-nadir viewing angles; also, some operators compare revisit times at a typical latitude while others compare at the Equator.

5- **Common Applications of Satellite Photogrammetry.** The four most common mapping projects that utilize satellite imagery include: (1) orthomosaics, (2) planimetric mapping, (3) classification mapping, and (4) topographic mapping. Each application is discussed below.

a. Orthomosaics. Most satellite imagery comes georeferenced but not orthorectified. Orthorectification is a process that corrects inherent distortions in the optics and viewing geometry. The process incorporates a satellite orbital model, a digital elevation model (DEM) and optionally photo-identifiable ground control points (GCPs). Orthorectification is the most reliable way to correctly georeference all points in an image.

(1) In addition to improving the absolute accuracy of the imagery, orthorectification also improves the relative spatial match across adjacent scenes and strips. However, if the source scenes have different or opposite look angles, some spatial mismatch may be unavoidable, especially in high-relief areas.

**Table 1-1. Comparison of High- and Medium-Resolution Commercial Imaging Satellites**

| Satellite System | Vendor | Spatial Resolution (meters) | Wavelengths (nanometers) | Radiometric Resolution | Temporal Resolution (days) |
|---|---|---|---|---|---|
| Ikonos<br>9/24/1999 | DigitalGlobe | Panchromatic: 0.83<br>Multispectral: 4 | Pan: 526-929<br>Blue: 445-516<br>Green: 506-595<br>Red: 632-698<br>NIR: 757-853 | 11-bit | 2.9 days at 1m<br>1.5 days at 1.5m |
| QuickBird<br>10/18/2001 | DigitalGlobe | At altitude 450 km<br>Panchromatic: 0.61<br>Multispectral: 2.44 | Pan: 405-1053<br>Blue: 430-545<br>Green: 466-620<br>Red: 590-710<br>NIR: 715-918 | 11-bit | 2.5 days<br>5.6 days at 20° off-nadir or less |
| SPOT-5<br>5/3/2002 | Astrium | Panchromatic: 2.5 and 5<br>Multispectral: 10 | Pan: 480-710<br>Green: 500-590<br>Red: 480-710<br>NIR: 780-890<br>SWIR: 1,580-1,750 | 8-bit | 2-3 days |
| WorldView-1<br>9/18/2007 | DigitalGlobe | Panchromatic: 0.5 | Pan: 400-900 | 11-bit | 1.7 days at ≤1m<br>5.4 days at 20° |
| RapidEye<br>9/29/2008 | BlackBridge | No Panchromatic<br>Multispectral: 5 | Blue: 440-510<br>Green: 520-590<br>Red: 630-685<br>Red Edge: 690-730<br>NIR: 760-850 | 12-bit | 1 – 5.5 days |
| GeoEye-1<br>9/26/2008 | DigitalGlobe | Panchromatic: 0.41<br>Multispectral: 1.65 | Pan: 450-800<br>Blue: 450-510<br>Green: 510-580<br>Red: 655-690<br>NIR: 780-920 | 11-bit | < 3 days |
| WorldView-2<br>10/8/2009 | DigitalGlobe | Panchromatic: 0.5<br>Multispectral: 2 | Pan: 450-800<br>Multispectral:<br>Coastal: 400-450<br>Blue: 450-510<br>Green: 510-580<br>Yellow: 585-625<br>Red: 630-690<br>Red Edge: 705-745<br>NIR1: 770-895<br>NIR2: 860-1,040 | 11-bit | 1.1 days at ≤1m<br>3.7 days at 20° off-nadir or less |
| Pléiades-1A<br>12/16/2011<br>Pléiades-1B<br>12/12/2012 | Astrium | Panchromatic: 0.5<br>Multispectral: 2 | Pan: 470-830<br>Blue: 430-550<br>Green: 500-620<br>Red 590-710<br>NIR: 740-940 | 12-bit | 1 day with two satellites |

**Table 1-1 (Continued)**

| Satellite System | Vendor | Spatial Resolution (meters) | Wavelengths (nanometers) | Radiometric Resolution | Temporal Resolution (days) |
|---|---|---|---|---|---|
| SPOT-6<br>9/09/2012<br>SPOT-7<br>Q1 2014 | Astrium | Panchromatic: 1.5<br>Multispectral: 6 | Pan: 450-750<br>Blue: 440-520<br>Green: 530-590<br>Red 630-700<br>NIR: 760-890 | 12-bit | 1 day with two satellites |
| WorldView-3<br>3Q, 2014 | DigitalGlobe | Panchromatic: 0.31<br>Multispectral: 1.24<br>SWIR: 3.7<br>CAVIS: 30.0 | Pan: 450-800<br>8 MS Bands:<br>Coastal: 400-450<br>Blue: 450-510<br>Green: 510-580<br>Yellow: 585-625<br>Red: 630-690<br>Red Edge: 705-745<br>NIR1: 770-895<br>NIR2: 860-1040<br>8 SWIR Bands:<br>SWIR-1: 1195-1225<br>SWIR-2: 1550-1590<br>SWIR-3: 1640-1680<br>SWIR-4: 1710-1750<br>SWIR-5: 2145-2185<br>SWIR-6: 2185-2225<br>SWIR-7: 2235-2285<br>SWIR-8: 2295-2365 | 11-bits/pixel<br>Pan and MS<br>(Multispectral)<br><br>14-bits/pixel<br>SWIR | <1 day at ≤1m<br>4.5 days at 20°<br>off-nadir or less |
| | | | 12 CAVIS Bands:<br>Desert Clouds: 405-420<br>Aerosol-1: 459-509<br>Green: 525-585<br>Aerosol-2: 620-670<br>Water-1: 845-885<br>Water-2: 897-927<br>Water-3: 930-965<br>NDVI-SWIR: 1220-1252<br>Cirrus: 1350-1410<br>Snow: 1620-1680<br>Aerosol-3: 2105-2245 *<br>Aerosol-4: 2105-2245 *<br>*Note: Aerosol-3 and -4 are parallel bands, designed to map cloud heights | | |

(2) If an area of interest (AOI) comprises more than one scene/strip, the imagery also can be tonally balanced. Tonal balancing matches colors that otherwise would vary across adjacent scenes due to a variety of factors, including atmospheric conditions and vegetation seasonality

across multiple imagery acquisition dates. In cases of extreme seasonality differences, it may not be possible to create an entirely seamless tonal match.

(3) Typically, tonal balancing only is applied to land areas, not water, as the appearance of water features, especially saltwater, can vary greatly across multiple dates/scenes. If a visually pleasing or realistic picture is desired, water areas can be manually manipulated with software tools such as Photoshop, but image intelligence, such as shallow water depth, would be lost.

(4) To the extent possible, limiting the seasonality differences across strips helps improve tonal balancing. If an AOI comprises multiple scenes, some satellite operators will crop out part of the overlap area to reduce the file size. From an image processing perspective, however, especially where imagery needs to be cloud-patched, the overlap is desirable and should be available at no extra charge, as long as it's requested when the order is placed. Figure 1-1 and Figure 1-2 show how multiple overlapping scenes can be used to output a tonally balanced orthomosaic with cloud patching.

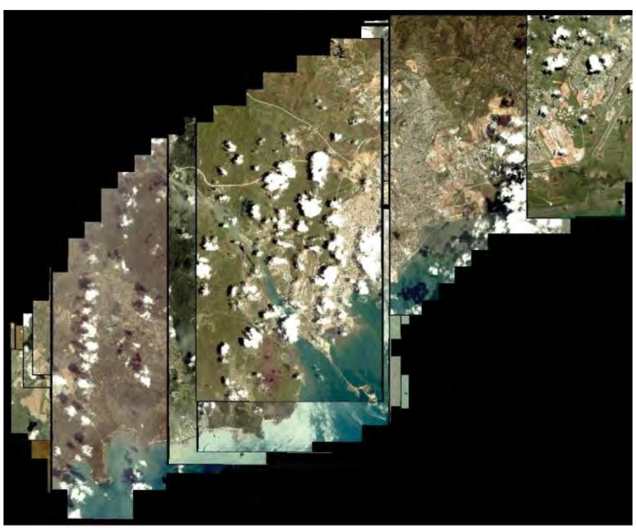


**Figure 1-1. Overlapping satellite image scenes with clouds**

**Figure 1-2. Tonally balanced orthomosaic produced with cloud patching**

(5) When creating orthomosaics, limiting the number of scenes facilitates processing, and, if applicable, helps reduce the total number of optimal Global Positioning System (GPS) GCPs. In the United States, public-domain products, such as imagery from the National Agriculture Imagery Program (NAIP), can be used as control to improve the ortho accuracy of imagery with lower native accuracy. Outside of the United States, if GPS GCPs aren't available, ideally the next-generation imaging sensors with higher native accuracy, such as GeoEye-1, WorldView-1 and WorldView-2, should be favored.

(6) Consideration should be given to the DEM being used. In the United States, 10-meter (1/3-arc-second) DEMs from the National Elevation Dataset (NED) are the best public-domain option for Hawaii and the 48 conterminous states, but unacceptable for orthorectification in Alaska. Alaska is currently being mapped with 5-meter DEMs from airborne interferometric synthetic aperture radar (IFSAR); the IFSAR portion of the Alaska Statewide Digital Mapping Initiative (SDMI) is expected to continue until at least 2017, depending on available funding. The National Digital Elevation Program (NDEP) also tracks the availability of high-accuracy, high-resolution DEMs from light detection and ranging (LiDAR) mapping of major urban areas and other high priority areas nationwide. As of 2012, approximately 28 percent of the U.S. was mapped with some form of LiDAR. Outside the United States, commercial and/or local government DEM options are available. However, if DEM selection is limited to public-domain options, despite the resolution difference, 90-meter (3-arc-second) Shuttle Radar Topography Mission (SRTM) data, which uses synthetic aperture radar (SAR) to penetrate clouds, will likely yield better results than some higher-resolution satellites, especially in areas with high cloud cover and/or low contrast (snow, dense vegetation, etc.). Also, imagery that has already had a DEM applied to it, including the Standard format from DigitalGlobe, isn't suitable to be orthorectified – the Ortho Ready format should be selected instead.

b. Planimetric Mapping. Vector extraction from satellite imagery allows roads, hydrology, building footprints and other planimetric features to be mapped cost effectively, or to update existing maps. The resulting accurate, up-to-date base data then are used to support the applications such as Internet mapping portals and handheld GPS devices.

(1) Unlike classification maps, which require multispectral imagery to emphasize the spectral properties of various features, feature extraction is based on spatial properties – the size and shape of objects – so pan imagery can be used. Color imagery, however, makes it easier to identify certain features such as water, paved vs. unpaved roads, etc.

(2) Despite advancements with machine learning and object-based image analysis, features such as roads, streams, and building footprints are still often captured via manual heads-up digitizing from orthomosaics. Computer-aided design (CAD) applications typically work best with 8-bit imagery, with a contrast stretch already applied to the

**Figure 1.3. Satellite imagery used for vector feature extraction of planimetric features.**

imagery. Especially in AOIs of high relief or those comprising more than one scene, imagery should be orthorectified prior to feature extraction. Figure 1-3 shows how satellite imagery can be used for vector extraction of roads, hydrology and other planimetric features.

(3) Wavelet compressed file formats, such as ECW, MrSID and JPEG 2000, help facilitate file transfer across multiple production/quality assurance teams. Otherwise, it may help to tile GeoTiff imagery, as some CAD programs are limited in their ability to work with large raster files. Whenever possible, seasonality consideration should be given to AOIs, as leaf-off imagery yields better feature visibility.

c. Classification Mapping. Classification maps are one of the most common types of products created from satellite imagery and can map broad categories of land cover such as forest vs. agriculture or specific plant species. They also can map land use such as urban, industrial, residential, suburban and open space. These types of "clutter" maps are used in radio-frequency modeling for wireless networks, among other applications. Traditionally, classification work has been spectral pixel-based, so 11-bit, four-band imagery or better is used; newer object-based image analysis methodologies can yield superior results, especially with high-resolution imagery and image datasets that may only be available as three-band and/or 8-bit. Figure 1-4 and Figure 1-5 demonstrate how multispectral and infrared imagery is useful for classification mapping projects such as vegetation mapping.

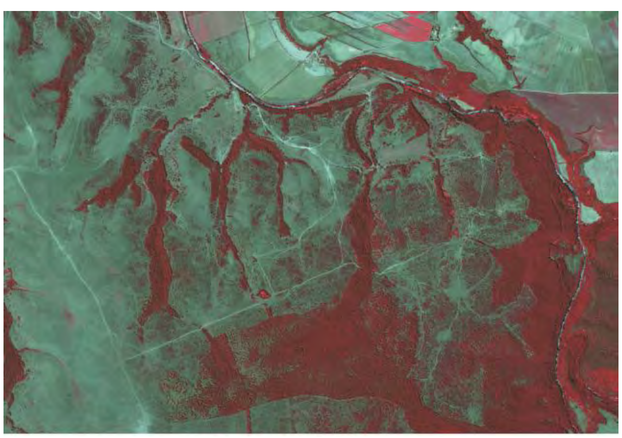


**Figure 1-4. Multispectral and infrared imagery**

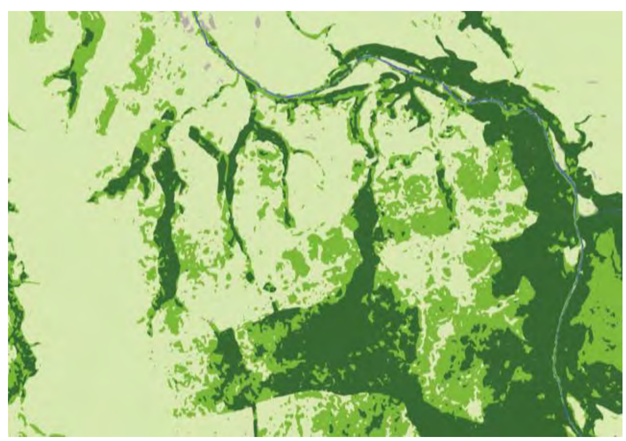


**Figure 1-5. Classification map of vegetation**

d. Topographic Mapping. Cloud-free stereo imagery is required for topographic mapping from either aerial photogrammetry or satellite photogrammetry. In parts of the world where it is possible to obtain cloud-free optical high-resolution satellite imagery, this may be the preferred solution when producing Digital Elevation Models (DEMs) for applications with required resolutions down to 1-meter and where dense forests do not block stereo views of the bare-earth terrain. Topographic mapping can also be performed using radar satellites such as TerraSAR-X and TanDEM-X which operate in tandem to create a three-dimensional map of the world; but this technology is best suited for tropical areas where 10-meter DEM resolution is acceptable.

5- **Geo-positioning.** Satellite images must undergo extensive post processing in order to be accurately georeferenced to a degree suitable for photogrammetric mapping. Vendors employ rigorous sensor models in order to orient an image's two-dimensional horizontal coordinates to the three-dimensional earth. These sensor models are developed based on the specifications of the image sensor as well as the satellite's orbit trajectory and velocity. In addition, the degree of accuracy in which satellite imagery is delivered may not be suitable for photogrammetric applications without GCPs established independently of the sensor model.

a. Orientation Types. Satellite imagery can be delivered as either an orthorectified or stereographic product. Orthorectified imagery, referred to as orthoimagery, is processed to correct distortions caused by relief displacement. In order to orthorectify a satellite image, a Digital Elevation Model (DEM) must be used in conjunction with rational polynomial coefficients provided by the vendor.

(1) Rational Polynomial Coefficients. Due to the complexity of the rigorous sensor models used to orient satellite imagery, vendors will instead deliver rational polynomial coefficients (RPCs) that can be digested by commercial photogrammetry applications. Rational polynomial coefficients, also referred to as Rational Polynomial Camera models, are calculated from a satellite's sensor model in order to relate an image's horizontal and vertical orientation to the Earth surface, for example latitude, longitude, and surface elevation. RPCs are included as part of a deliverable for use in orthorectification in the event a user needs to update the imagery using a more recent or high resolution DEM. Also, if the initial accuracy of the imagery does not meet project requirements, RPCs can be updated using supplementary ground control points.

(2) Epipolar Geometry. In order to view satellite imagery in a stereographic workstation, the imagery must be rectified using epipolar geometry, which is the framework for stereographic viewing (Figure 1-6). Given a pair of images, epipolar rectification transforms each image plane so that the pairs of epipolar lines become co-linear and parallel to the epipolar plane. The epipolar plane is defined as, for a given ground point visible in each image of a stereo pair, the plane passing through the point and the two camera stations. An epipolar line is formed by the intersection of the epipolar plane with either a horizontal ground space plane or one of the images used to compute the epipolar plane. To visualize stereo, both the left and right images must be oriented so the epipolar line is horizontal. Stereo pairs can be produced by Iconos, WorldView, SPOT and Pléiades satellite systems listed in Table 1-1. Once stereo pairs are acquired, photogrammetric software suites provide the functionality to perform epipolar rectification.

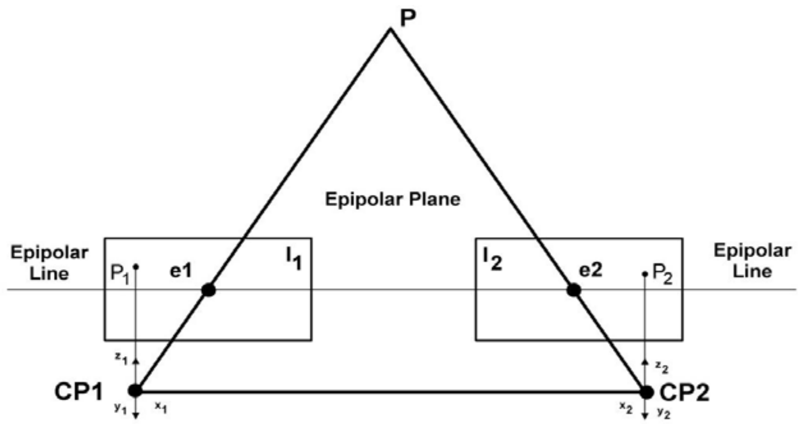



**Figure 1-6. Epipolar Geometry**

b. Accuracy. The horizontal and vertical accuracy of satellite imagery will not necessarily support high accuracy photogrammetric applications. Examining the horizontal accuracy specifications in Table 1-1, a satellite capable of producing imagery that achieves a horizontal accuracy of 5-meters (CE90) for example, without ground control points (GCPs), may be able to achieve 1 or 2 meter accuracy with GCPs and rigorous photogrammetric aerial triangulation.

(1) Ground Control Points (GCPs). Ground control in satellite photogrammetry is conducted differently than that of traditional aerial photogrammetry or land surveying. Due to the size and remoteness of an area, photogrammetrists will utilize virtual ground control points to orient imagery, instead of physical ground control points established by survey. These points may be sourced from ancillary data such as orthoimagery or a satellite's onboard telemetry. However, this type of ground control does not support photogrammetric mapping; therefore physical, photo-identifiable GCPs should be acquired to increase image accuracy. Typically ground control that is three times better than the final product designation should be acquired. For example, a final deliverable requirement of 3-meter RMSE requires ground control with at least 1-meter RMSE quality.

(2) Aerial Triangulation (AT). Due to the cost of acquiring physical GCPs and the potentially large area of a satellite photogrammetry project, aerial triangulation is used to extend horizontal and vertical control from known GCPs to each unknown GCP in the solution. Aerial triangulation is critical when satellite imagery is to be used in a photogrammetric workstation because it serves to orient each stereo model, ensuring reliable stereo viewing and geo-positional accuracy. This is especially important considering the relatively low horizontal accuracy in respect to aerial imagery and the large image swaths inherent with satellite imagery listed in Table 1-1. Essentially, as the number of stereo models, aerial extent, and topographic relief of a project increases, so does the need for aerial triangulation in order to extend the ground control network.

**Creating Satellite Imagery Stereo Pairs.** Most high resolution imaging satellites are pushbroom sensors that not only can look forward, downward or backward, but can also roll to the left or right to capture target areas of interest (AOIs), adding to the complexity of the stereo model acquisition geometry. Images in this section were provided as a courtesy by Digital Globe. Figure 1-7 shows fore/aft stereo imagery derived from the same pass (in track) over a target with camera looking forward in the first collect (fore) and backward in the second collect (aft).

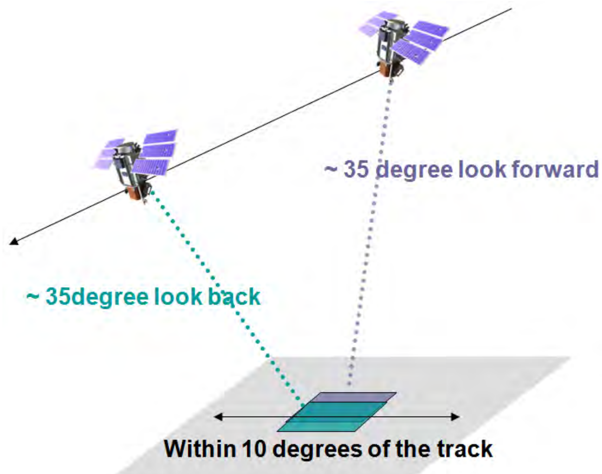



**Figure 1-7. Satellite stereo image acquisition**

a. Stereo Model Acquisition Geometry. Section 1-4 (a) (2) introduced the concept of epipolar geometry. Figure 1-8 helps readers understand the additional definitions below.

Epipolar Plane — the plane formed by the two rays from the ground point to the perspective centers.

Convergence (C) — the angle in the epipolar plane between the two rays from the ground point to the perspective centers.

Asymmetry (A) — the angle between the bisector of the convergence angle and the projection of the local vertical onto the epipolar plane.

Roll (R) — the angle between the epipolar plane and the local vertical.

Bisector Elevation (BIE) — the elevation of the bisector of the convergence angle.

Base/Height Ratio (B/H) — ratio of the air base (length of epipolar line between L1 and L2 at Figure 1-8) and height of the epipolar line above terrain height (point P).

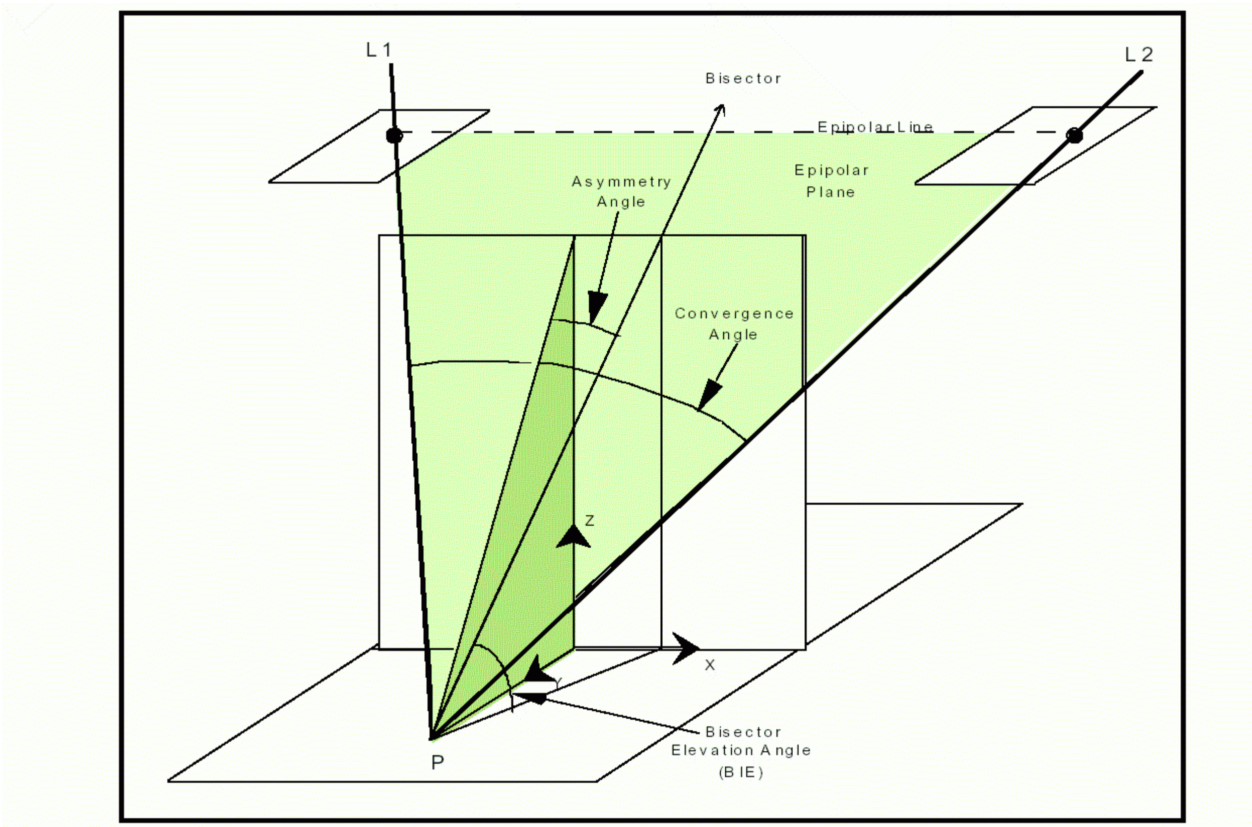


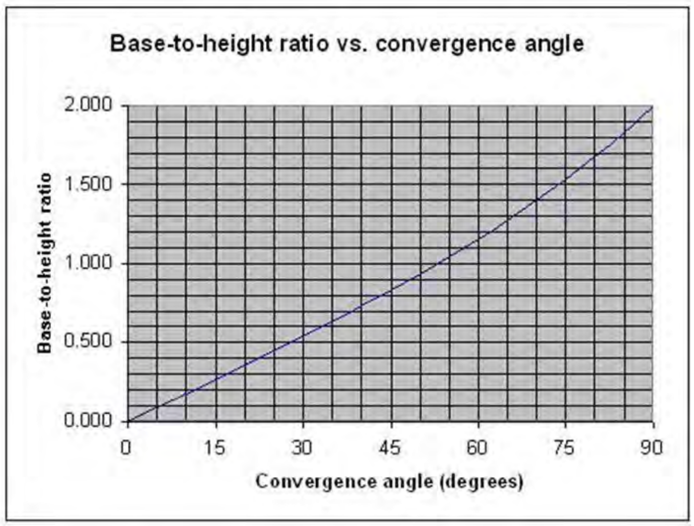

**Figure 1-8. Epipolar plane, asymmetry angle, convergence angle, and bisector elevation angle (from STDI-0002)**

b. Convergence Angles. Lower convergence angles provide better stereo fusibility which is the ease to which the stereo images can be viewed/processed. Lower convergence angles imply two images that are closer in time and space, resulting in pixels that are more similar in size and orientation. Similarity of pixels in size and orientation helps to provide better matches between the two images, be they matches in the human brain to see stereo or matches of interest/tie points with conjugate points in the other image as found by automated point/terrain extraction software. However, lower convergence also implies more parallel rays which make z/height estimation less accurate than larger angles. High convergence angles provide better z-value estimates. High convergence angles imply two images that are taken further apart in time and space resulting in differing pixel sizes and orientations. Ray intersections are more precise as a result of the larger angle. To overcome a lack of stereo fusibility with larger convergence angles, an epipolar rectification can be performed to minimize differences in pixel size and orientation. Epipolar rectification is projection to a plane formed by the ground point and the two perspective center. It is important to balance fusibility with z-accuracy requirements. The convergence angle (C) should be between $30^o$ and $60^o$.

c. Asymmetry, Roll and BIE. Asymmetry (A) and Roll (R) are both negatively correlated with fusibility; therefore Asymmetry and Roll should both be kept small. The Bisector Elevation Angle (BIE) combines the effect of both Asymmetry and Roll and should be near 90° to keep Asymmetry and Roll small. An empirical study by Cain (1989) shows that (BIE – C) is strongly correlated with fusibility. (BIE – C) > ~20° is recommended for comfortable stereo fusion.

d. Base/Height Ratio. At Figure 1-9, the preferred Base/Height ratios are highlighted in blue.

| Convergence Angle (degrees) | Base-to-height ratio |
|---|---|
| 0 | 0.000 |
| 5 | 0.087 |
| 10 | 0.175 |
| 15 | 0.263 |
| 20 | 0.353 |
| 25 | 0.443 |
| 30 | 0.536 |
| 35 | 0.631 |
| 40 | 0.728 |
| 45 | 0.828 |
| 50 | 0.933 |
| 55 | 1.041 |
| 60 | 1.155 |
| 65 | 1.274 |
| 70 | 1.400 |
| 75 | 1.535 |
| 80 | 1.678 |
| 85 | 1.833 |
| 90 | 2.000 |




B/H = 2*tan(C/2)
(asymmetry = 0 and bisector elevation = 90 degrees.)

**Figure 1-9. Relationship between stereo convergence angle and the base/height ratio.**

## 5-Ten Things to Consider in Buying Optical Satellite Imagery.

a. Spatial Resolution. Image resolution is the first number looked at and the one that grabs the headlines. Resolution, however, can refer to multiple parameters. For example, temporal resolution measures how frequently a satellite can image a target. But more commonly, spatial resolution is used to describe the level of detail that can be seen in the image. As shown at Figures 1-10 and 1-11, an image with 1-meter spatial resolution, where each pixel represents a ground distance of 1 meter x 1 meter, has higher resolution – is more detailed – than a 5-meter resolution image where each pixel represents a ground distance of 5 meters x 5 meters. Note that these two figures are not shown at the same scale, but Figure 1-10 is already blurry before zooming in to a larger scale as in Figure 1-11. The native ground sample distance (GSD) of images varies based on collection geometry, but images are subsequently re-sampled to a uniform resolution.

(1) When zoomed out far enough, high- and medium-resolution imagery looks the same. The difference becomes apparent when zooming in closer, as the high-resolution imagery – typically 1 meter or less – will display greater feature detail and show smaller features. Although digital imagery doesn't have an inherent scale, higher spatial resolution will support viewing/plotting at a larger scale (see Table 1-1).

**Figure 1-10. Image with 5-meter resolution.**

**Figure 1-11. Image with 1-meter resolution.**

(2) Resolution selection is often driven by the size of the area of interest (AOI). Due to cost and technical considerations, high-resolution imagery usually is selected for AOIs smaller than 500 square kilometers, whereas medium-resolution imagery can offer a cost savings for AOIs 500 square kilometers and larger. Besides higher cost, disadvantages of high-resolution imagery include larger file size (caused by an exponential relationship between resolution and file size) and smaller swath widths – the width across a single scene/strip of imagery.

b. Spatial Accuracy. Although there is typically some level of correlation between spatial resolution and accuracy, there are notable exceptions. Compared with DigitalGlobe's QuickBird satellite, for example, the company's WorldView-1 and WorldView-2 satellites offer only a moderate enhancement to spatial resolution, but because they employ new technology, they achieve significantly improved native accuracy. Most satellite imagery is delivered georectified or georeferenced, but not orthorectified, which is a process that improves absolute accuracy by correcting for terrain displacement. Therefore, the accuracies listed in Table 1-1 are exclusive of terrain displacements, which is significant in areas of high relief. Typically, horizontal accuracy is expressed as CE90 (Circular Error, 90 percent), but it may also be expressed as RMSE (Root Mean Square Error) or as a scale. For example, to comply with U.S. National Map Accuracy Standards for 1:12,000-scale, an orthorectified image would need to achieve 10 meter CE90 accuracy or a radial RMSE of 6.7 meters.

c. Off-Nadir Angle/Elevation Angle. In practice, collecting an image at nadir, i.e., looking straight down at the target, doesn't happen with high-resolution satellite imagery; satellite sensors always shoot at an angle. This agility improves imaging revisit times and, with some satellites, enables stereo collects for 3-D elevation modeling. Satellite operators may report this either as "elevation angle," where 90 degrees is looking straight down, or "off-nadir angle," where 0 degrees would be looking straight down. A typical minimum is an elevation angle of 60 degrees, which is a 30-degree off-nadir angle. A high-elevation angle (lower off-nadir angle) often is desirable, especially in areas of high relief or tall buildings to minimize what's known as the building-lean effect. However, the desire for a higher elevation angle must be weighed against the resulting decreased imaging revisit time. A 70-degree or higher elevation angle (20 degree or less off-nadir angle) decreases the number of potential attempts the satellite can make in a given time period, making a successful new collect less likely. Figure 1-12 shows how satellite agility increases collection effectiveness and allows some sensors to perform in-line (same-pass) stereo collection.

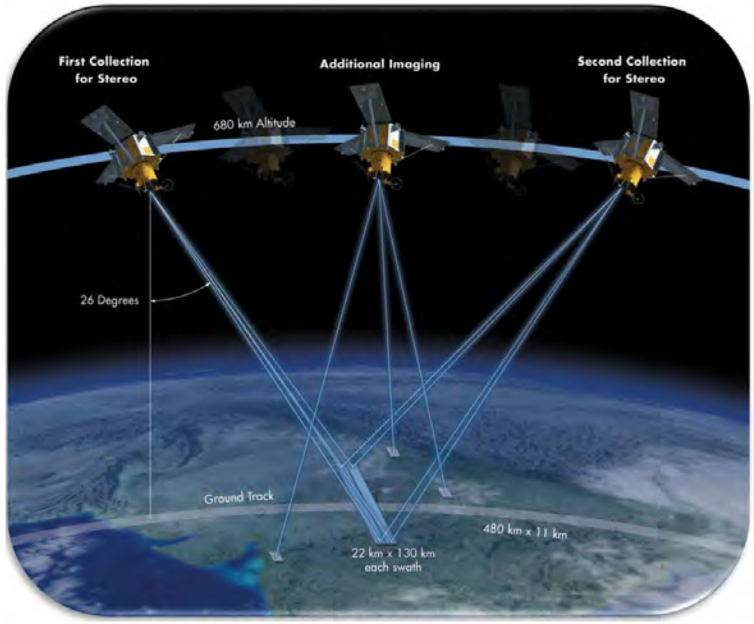



**Figure 1-12. Satellite agility enables the satellite to point in different directions and collect imagery off-nadir.**

d. Sun Elevation. Sun elevation is the angle of the sun above the horizon. Imagery collected with low sun elevation angles may contain data that are too dark to be usable. A typical minimum sun elevation angle is 30 degrees, but adhering to this requirement means that northern

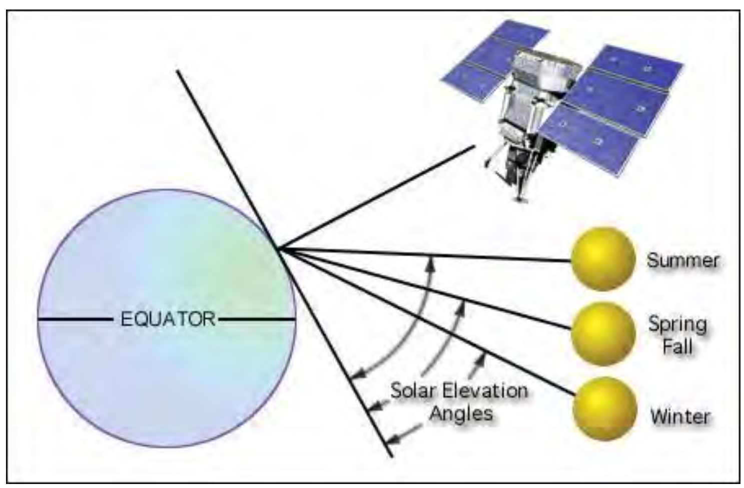



**Figure 1-13. Changes in sun elevation angle cause variations in the illumination conditions under which imagery is obtained.**

latitudes above 35 degrees will have black-out periods during the winter months when imagery with an acceptable sun elevation angle can't be collected. Figure 1-13 shows the changing sun elevation above the horizon during summer, spring/fall, and winter. In the northern hemisphere, sun elevation angles in the summer months are most favorable, casting much smaller shadows than winter months when sun elevation angles are much smaller.

(1) Decreasing the minimum required sun elevation angle to 15 degrees means that only northern latitudes above 50 degrees will have a black-out period; even a 30-degree sun angle is low for many applications. For example, increased shadow areas are problematic for classification and stereo projects. This will be more pronounced in high-relief areas and areas with taller objects, such as trees and buildings, where low sun elevation angles mean longer shadows will be cast.

(2) For some of the affected land masses, these black-out periods correspond to months with snow cover, making new collects during these times less desirable regardless. In areas such as Alaska, where sun angle and snow cover limit the window for optimal imaging, optical satellites are currently unable to meet some of the high demand for imagery.

e. Spectral Information. This section pertains to imaging bands, bit depth, and dynamic range adjustment bands. Each imaging band measures different wavelengths of light. Most commercial optical imaging satellites capture panchromatic (pan, viewed as monochromatic gray scale) imagery at higher resolution, and four multispectral (MS) bands – red, green, blue and infrared – at one-fourth the resolution to support a colorization process called pan-sharpening. Notable exceptions to this include WorldView-1 (pan only); WorldView-2 (pan + eight MS bands instead of the typical four MS bands); WorldView-3 (pan + eight MS bands + 8 SWIR bands + 12 CAVIS bands), and RapidEye, which acquires five MS bands but no pan imagery (see Table 1-1). CAVIS is a new term from DigitalGlobe that refers to Clouds, Aerosols, water Vapor, Ice and Snow.

(1) The most common format for typical users is true or natural color, which is three-band RGB (red, green, blue) pan-sharpened, as most users desire the combination of color and spatial detail. However, advanced users performing classification or analysis generally prefer four-band imagery because the infrared band is helpful for vegetation analysis (see Figure 1-4 above).

(2) Smaller file size used to be considered an advantage of pan imagery, but with increased computing capability, that has become less of a constraint. Pan imagery remains the preferred format for digital elevation model (DEM) generation from stereo pairs. When importing multiband imagery, different combinations can be selected. Four-band imagery 3-2-1 typically corresponds to true/natural color, whereas 4-3-2 represents false color/infrared.

(3) Bit depth is critical. Beginning with GeoEye's IKONOS satellite, all leading high-resolution commercial imaging satellites capture 11-bit imagery, meaning a maximum of 2,048 digital numbers (DNs) per band instead of the earlier 8-bit/256 levels. RapidEye's satellite constellation and Astrium's Pléiades satellite offer the additional advantage of collecting 12-bit imagery. Improved bit depth aids the ability to discern detail in an image's brightest and darkest (shadow) areas. Most computers require data in 8-bit format, so an 11- or 12-bit image can have the color table (DNs) downsampled to 8-bit or upsampled to 16-bit. In this case, the four or five unused bit locations are filled with zeros, creating a 16-bit file format but not a true 16-bit image. Imagery used for classification or analysis, or that which must be tonally balanced, always should be ordered in 16-bit format. For many users, however, there is convenience to using 8-bit imagery – smaller file sizes and no software compatibility issues.

(4) Dynamic range adjustment (DRA) is also critical. When delivering 8-bit imagery, high-resolution satellite operators typically will perform an automated process to adjust contrast and brightness. DRA offers a time savings for "load-and-go" imagery, so a user can avoid running a manual adjustment. This is prone to fail in certain areas, however, such as a desert where the color spectrum isn't balanced. In such instances, a manual adjustment will yield better results. Manual contrast adjustment also tends to work better with pan imagery. Figure 1-14 and Figure 1-15 show the dramatic affects on an image's visual interpretability whether DRA is off or on.

**Figure 1-14. Dynamic range adjustment off.**

**Figure 1-15. Dynamic range adjustment on.**

f. Projection. Although many programs now perform "on-the-fly" reprojections, ordering imagery in the same projection as other project data being used is still desirable. Stereo imagery for DEM generation often will be ordered as epipolar; however, a Universal Transverse Mercator (UTM) ortho can be output later. Because satellite operators offer a limited selection of projections, supporting a region-specific datum may require a custom reprojection.

g. Resampling Method. Cubic convolution is typically the default resampling method for Earth imagery, but the enhanced kernel – a hybrid of cubic convolution – is recommended for DigitalGlobe's pan-sharpened products. For research applications, where image data may be converted to radiance values, nearest-neighbor resampling offers the advantage of not introducing any new values to the imagery, but it can introduce what appear to be geometric and color defects. Most imagery users wouldn't be satisfied with the appearance of imagery processed with the nearest-neighbor method.

h. Collection Capacity. Because high-resolution imaging satellites are able to shoot off-nadir, their revisit times – ability to repeat coverage of the same AOI – is three days or less. Employing multiple high-resolution satellites on the same AOI means that intraday revisits are theoretically possible. However, in the real world, clouds and competition for satellite time are significant obstacles.

(1) A satellite's collection capacity is determined by its swath width (see Table 1-1), agility to point and shoot at multiple targets or capture multiple adjacent strips for large-area mapping on the same orbital pass, onboard storage and downlink capacities. Pléiades 1, GeoEye-1, WorldView-1 and WorldView-2, and other satellites offer significantly improved collection capacities than their predecessors, while the older satellites, such as IKONOS and QuickBird, may have better available capacity to collect an AOI in regions where the newer satellites have demand backlogs.

(2) A satellite such as Pléiades 1, which doesn't have a U.S. government backlog, also may be able to offer faster commercial tasking. Tasking two or more satellites for the same AOI improves the ability for imagery to be captured. For example, DigitalGlobe offers constellation order fulfillment (COF) where QuickBird and WorldView-2 can be tasked to acquire the same AOI with no cost uplift. RapidEye further leverages the constellation concept by employing a system of five identical satellites to facilitate country, and regional-scale mapping and saturating coverage of areas with persistent cloud cover. See Figure 1-16.

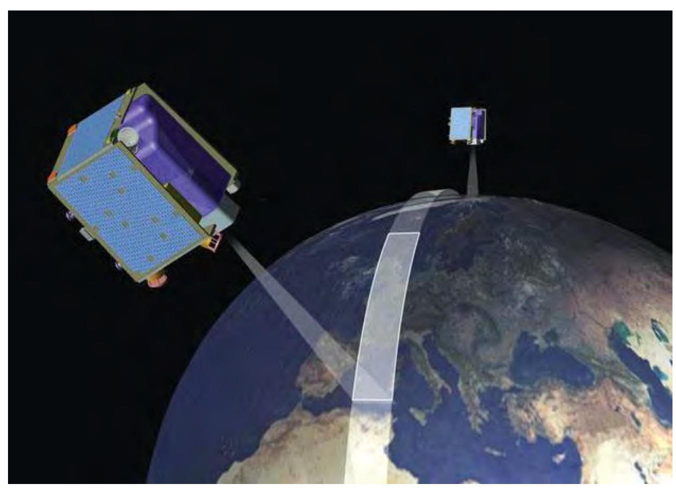


**Figure 1-16. RapidEye's constellation approach permits a cumulative swath to be built up as multiple satellites view adjacent regions of the ground.**

(3) When placing a new collect order, a feasibility assessment typically will be run to estimate the turn-around time. The feasibility takes into account potential cloud cover for the

region and competition for satellite time in the area. Because collection queues can change daily and cloud cover is uncontrollable, feasibilities are only estimates, not guaranteed collection times. Most satellite operators offer priority tasking for an additional charge. Areas that have both high demand for imagery and persistent cloud cover are challenging to collect regardless of time of year and are likely to require lengthy turn-around times.

(4) It's important to note that due to sun-synchronous orbits, there is little control over the time of day an AOI is imaged. Collects, which are made only on the descending orbit, typically are made around 10:30 a.m. local time over a desired AOI. Because high-resolution imaging satellites orbit Earth 15 times a day, an interesting exception to this is polar latitudes. Because Earth narrows at extreme latitudes, intra-day collects via the same satellite are possible, presuming an acceptable sun angle.

i. Cloud Cover. Typical cloud-cover guarantee with new collections is 15 percent or less within the project AOI. Some satellite operators offer an improved cloud-cover guarantee for a cost uplift or the ability to choose a small cloud-free target area that must have zero cloud cover. This option is well suited for infrastructure sites such as airports, mines, and oil and gas installations. Typically, if the satellite operator can't deliver a new collect that meets order specifications during the estimated collection window, the customer can either extend the collection window or cancel the order at no charge. With archived imagery, a reduced-resolution preview graphic can be reviewed ahead of time, although it can be difficult to detect small clouds or haze. Where persistent cloud cover is the major issue with imaging satellites, synthetic aperture radar (SAR) imagery from satellites (e.g., Shuttle Radar Topography Mission, RADARSAT-2, TerraSAR-X and TanDEM-X) should be considered.

j. Delivery Method. Traditional delivery methods have been file transfer protocol (FTP), digital video disk (DVD) and external hard drive. As FTP capabilities have improved and the cost of external hard drives has come down, DVD is being used less frequently. Before ordering a large area with DVD delivery, it's worthwhile to consider the time required to upload from DVD to hard drive vs. the extra cost of delivery on external hard drive. Heavy imagery users also will benefit from an upgrade to USB 3.0.

(1) Although this chapter discusses parameters dealing with ideal imagery collection scenarios, real-world cost and turn-around time constraints often mean imagery users will need to consider available imagery. For example, in a high cloud cover/high tasking competition, the best option may be to use a less than optimal archived image because a new collect likely would require a lengthy turn-around time and not come back entirely cloud-free.

(2) In such instances, an experienced geodata professional can help users understand the acceptable trade-offs for a proposed project. Working with an independent data company, often called value-added resellers (VARs) or channel partners, can help ensure the optimal imagery

solution for a specific project area instead of limiting the range of options to one satellite operator. VARs typically offer imagery at the same price as the source company.

(3) A specialized data company can source DEMs and ground control as needed and can offer custom processing and flexible delivery options. For example, imagery can be ortho output as 16-bit pan plus MS for users with more advanced remote sensing software and three-band, 8-bit pan-sharpened mosaics with contrast adjustment, in GeoTiff and wavelet compressed formats, for users with daily computer-aided drafting (CD), geographic information system (GIS) and graphics software applications.

(4) In areas where the selection of archived imagery is limited, a value-added vendor can combine imagery from multiple sensors into the same mosaic. In addition, products can be processed to complement each other. For example, high-resolution imagery with superior native accuracy can be used as control to improve the accuracy of medium-resolution images covering larger areas.

(5) Along with the leading commercial optical satellite imagery products, many additional optical imagery solutions exist. Where available, aerial photography (panchromatic and multispectral) can be an alternative to high-resolution satellite imagery, as discussed in Chapter 4. The Japanese satellite ALOS no longer is collecting new imagery, but archived imagery collected during its five-year lifespan is available at moderate cost. The range of other imaging satellites is too numerous to list, but includes options such as KOMPSAT, EROS, FORMOSAT, the IRS constellation, Resourcesat and Cartosat, among other sensors. Public-domain Landsat and low-cost ASTER imagery can facilitate projects where commercial imagery may be cost-prohibitive. Both Landsat and Astrium's SPOT Image products offer extensive historical imagery archives.

1. **Which of the following is a common mapping project that utilizes satellite imagery?**
   - Orthomosaics
   - Planimetric mapping
   - Classification mapping
   - Topographic mapping
   - All of the above

2. **What is a process that corrects inherent distortions in the optics and viewing geometry?**
   - Planimetric mapping
   - Topographic mapping
   - Orthomosaics
   - Classification mapping

3. **The vendor Blackbridge operates what satellite system?**
   - Ikonos
   - GeoEye-1
   - Rapideye
   - SPOT-5

4. **What is vector extraction from satellite imagery allows roads, hydrology, building footprints and other features to be mapped cost effectively, or to update existing maps?**
   - Orthomosaics
   - Planimetric Mapping
   - Topographic mapping
   - Classification mapping

5. **True or False? Classification maps are one of the most common types of products created from satellite imagery and can map broad categories of land cover such as forest vs. agriculture or specific plant species.**
   - True
   - False

6. **Satellite images must undergo ___________________ in order to be accurately georeferenced to a degree suitable for photogrammetric mapping.**
   - slight processing
   - extensive post processing
   - a quality control review
   - subtle enhancement

7. **What type of ground control points (GCPs) are used for satellite photogrammetry?**
   - Physical
   - Virtual
   - Aerial
   - Major

8. **__________ convergence angles imply two images that are closer in time and space, resulting in pixels that are more similar in size and orientation.**
   - Lower
   - Higher
   - Acute
   - Obtuse

9. **What is the typical minimum sun elevation angle?**
   - 0 degrees
   - 15 degrees
   - 30 degrees
   - 45 degrees

10. **True or False? High-resolution imaging satellites typically orbit the Earth 15 times a day.**
    - True
    - False