TUTORIAL

Extraction of Geospatial Information from High Spatial Resolution Optical Satellite Sensors

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Section 5

Orthoimage Generation

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Need Aspect

- Images acquired through satellite or airborne sensors contain camera and terrain related distortions which make the images unsuitable for geospatial analysis as positions within the image may be significantly inaccurate.

- Orthorectification converts imagery into map-accurate form by removing camera and terrain related distortions from the imagery through the use of sensor and terrain (elevation) information. The resulting orthoimages, also known as orthomaps, can be directly applied in remote sensing, GIS and mapping applications.

Definition

Digital Orthophotographs, or variously orthophotos, orthophotoquads, orthos, orthoimagery or ortho rectified imagery are generally defined as *computer compatible aerial photographs, that have been geometrically corrected for displacements caused by terrain and relief.* In other words it is a picture prepared in such a manner that the perspective aspect of the picture has been removed.

Orthoimage is an image which shows ground objects in the orthographic projection.

Orthoimage -> orthogonal projection, image with map geometry

An **orthogonal projection** is the one in which the projecting rays are perpendicular to the plane of projection. Any part of the object that is parallel to the plane of projection will appear in its proper shape and correct scale
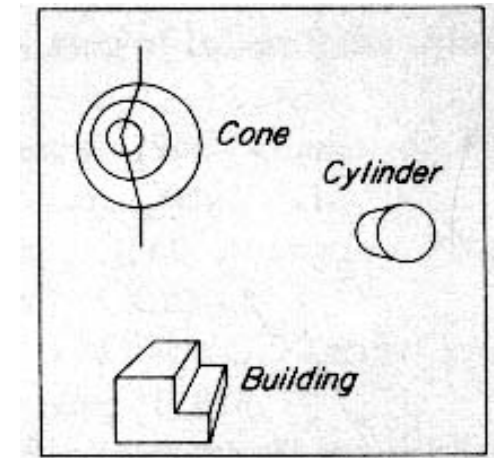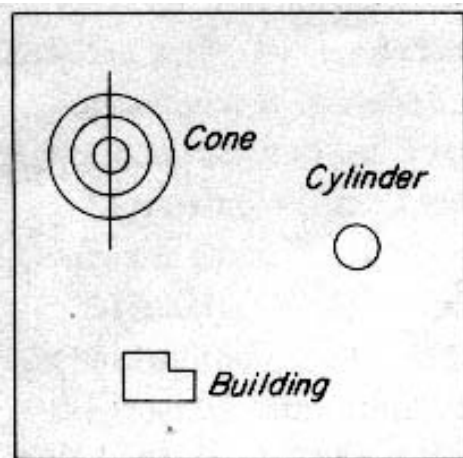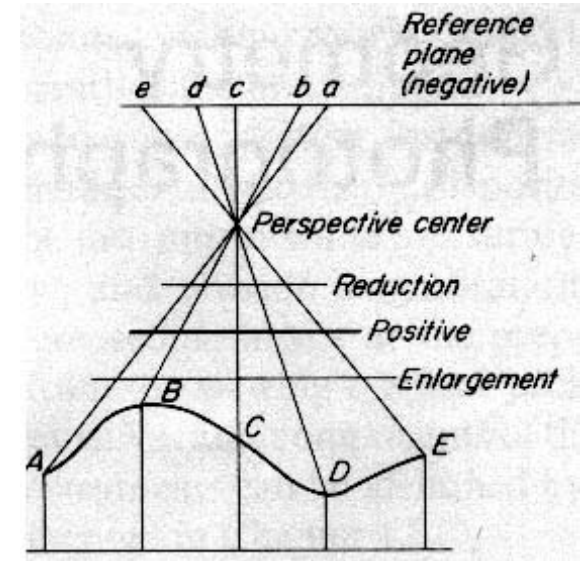
Orthogonal vs perspective projection
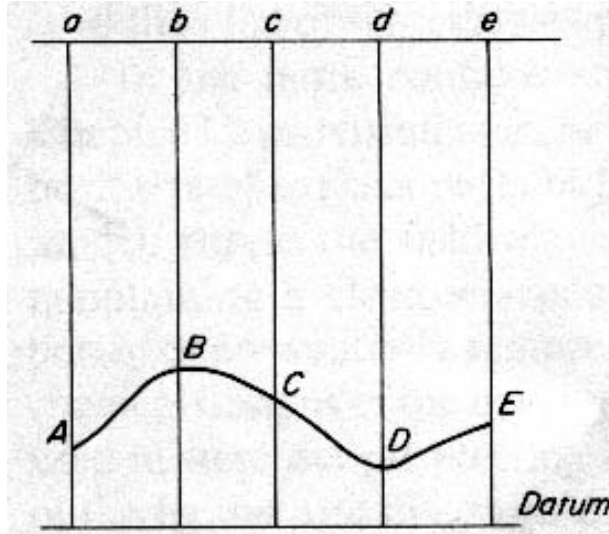
Orthogonal Projection

• Uniform scale

• No relief displacement

Perspective Projection

• Non-uniform scale

• Relief displacement

Idealised objects in orthographic and perspective projection

Where it is useful?

Because of the orthographic property, orthoimage can be used like a map for measurement of distances, angles, areas etc. with scale being constant everywhere, and also they can be used as map layers in GIS or other computer based manipulation, overlaying, analysis etc.

Orthoimage differs from a map in a manner of depiction of detail. On the map only selected detail is shown by conventional symbols, whereas on an orthoimage all detail appear just as in original satellite imagery. On the other hand satellite image without terrain correction differs from the orthoimage, in scale variation due to height and tilt distortions.

Preconditions for orthorectification
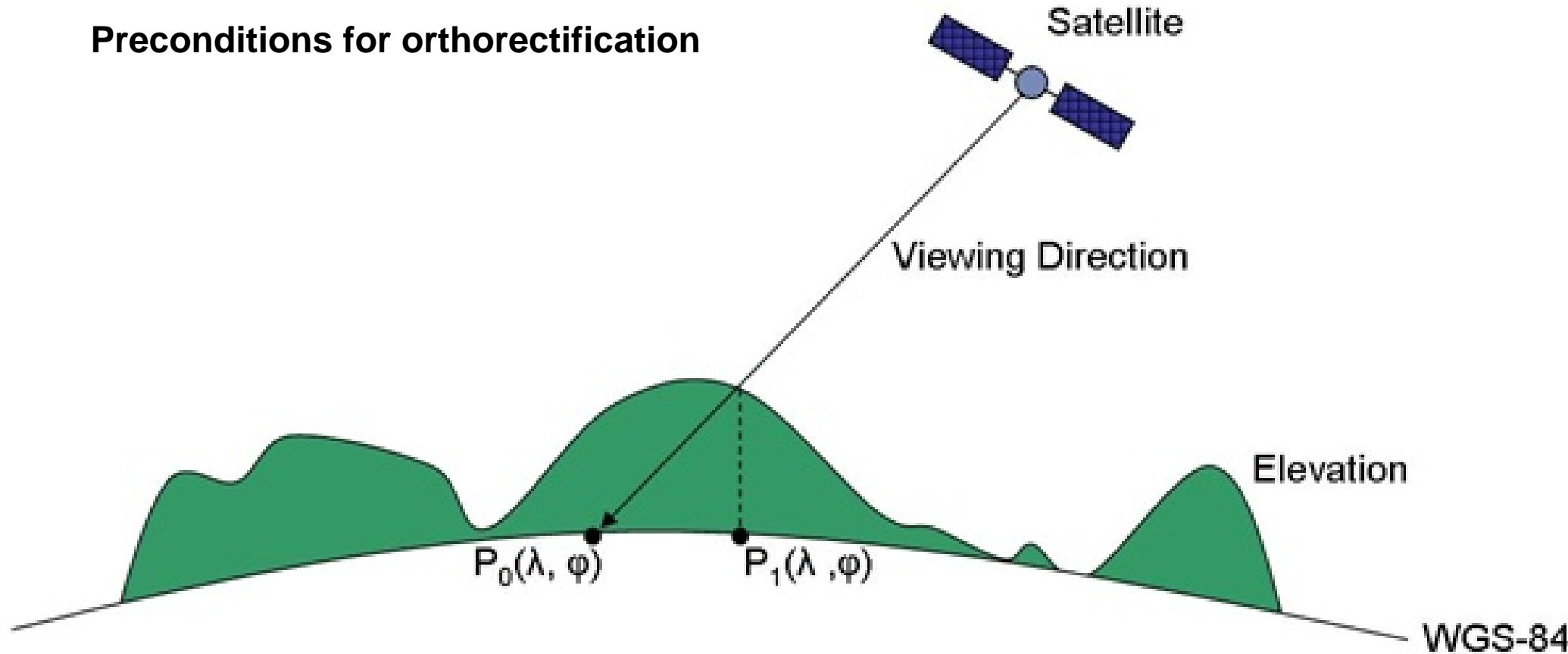
The geodetic point P_0 is the geo-location as provided by a basic data product. The geodetic point P_1 is the actual position of the measurement. The orthorectification is actually a map projection in which each pixel in the output product clearly identifies P_1. A simple map projection tries to find the pixel corresponding to P_0 in a given input product. The orthorectification tries to find the pixel corresponding to P_1 in a given input product

Orthorectification

In order to orthorectify the RAW imagery, a transformation model (to relate ground and image) is required which takes into account the various sources of image distortion generated at the time of image acquisition viz.,

- Sensor orientation (interior, exterior)
- Transformation from photo- in pixel-coordinate system (only with analog images)
- Topographic relief (DTM)
- Sensor orbit and attitude variations
- Systematic error associated with the sensor
- Optionally other correction values (lense distortion etc.,)

The required geometric parameters regarding sensor orientation at the time of image acquisition are determined through information on the sensor model, Ground Control Points (GCPs), and platform orbital or flight data (position, velocity, orientation).

Generation Method

- Refine/evaluate the transformation model using GCPs

-Define orthoimage grid for the area of interest (normally in object space)

- Choice of the orthoimage grid spacing W (usually as W = D/n),

   D ...DTM grid spacing, n ...integer > 1)

   "Rule of thumb": P/2 < W < 2P, P ...pixel size of original image in object space called also pixel "footprint"

   If W >> P, subsample the original image

-Projection of the orthoimage grid points in the digital image

- Grey level interpolation (resampling) on the RAW imagery to generate the final orthoimage

Orthorectification Models

• Parametric methods – knowledge of interior and exterior orientation parameters used

• Non-parametric methods – 2-D polynomial transformation functions

Polynomial rectification

The simplest way available in most standard image processing systems is to apply a polynomial function to the surface and adapt the polynomials to a number of checkpoints (GCPs). The procedure can only remove the effect of tilt, and can be applied on both satellite images and aerial photograph

$$r = \sum_{i=0}^{n} \sum_{j=0}^{n-i} a_{ij} x^i y^j \qquad (1)$$

$$c = \sum_{i=0}^{n} \sum_{j=0}^{n-i} b_{ij} x^i y^j \qquad (2)$$

Where r, c are pixel coordinates of input image (row and column); x, y are coordinates of output image; a, b are coefficients of the polynomial, and n is the order of the polynomial.

Projective rectification

To perform a projective rectification, a geometric transformation between the image plane and the projective plane is necessary

$$r = (a1x + a2y + a3) / (a7x + a8y + 1) \qquad (3)$$

$$c = (a4x + a5y + a6) / (a7x + a8y + 1) \qquad (4)$$

Where r, c are pixel coordinates of input image (row and column); x, y are coordinates of output image; a1 to a8 are coefficients.

Differential rectification

The objective of differential rectification is the assignment of grey values from the image (usually aerial image) to each cell within the orthophoto

$$x = x_0 - c\,\frac{r_{11}(X-X_0)+r_{21}(Y-Y_0)+r_{31}(Z-Z_0)}{r_{13}(X-X_0)+r_{23}(Y-Y_0)+r_{33}(Z-Z_0)} \qquad (5)$$

$$y = y_0 - c\,\frac{r_{12}(X-X_0)+r_{22}(Y-Y_0)+r_{32}(Z-Z_0)}{r_{13}(X-X_0)+r_{23}(Y-Y_0)+r_{33}(Z-Z_0)}. \qquad (6)$$

Where:

(x,y) are the coordinates of the point object in the image space

(x_0, y_0) are the image coordinates of the calibrated principal point (point of symmetry) of the camera;

c is the calibrated camera focal length;

(X_0, Y_0, Z_0) *are the coordinates of the camera station, and*

r_{ij} are the elements of the rotation matrix between the image and ground systems.

Sensor model rectification

Sensor models are required to establish the functional relationship between the image space and the object space. Sensor models are typically classified into two categories: physical and generalized models

The relationship between image and corresponding ground co-ordinates is established through physical imaging condition model in the form of collinearity conditions.

The modified collinearity conditions for satellite imaging geometry can be written as

$$(x, y, -f)^T = s\, M\, (X_A - X_S)$$

where $(x, y, -f)$ are image co-ordinates of a point, **s** is the scale factor, **M** is the transformation matrix

(X_A, Y_A, Z_A) are geocentric coordinates of a ground point
(X_S, Y_S, Z_S) are geocentric co-ordinates of the perspective center

Transformation Matrix **M** consists of 3 rotation matrices

$$M = R_L \cdot R_A \cdot R_O^T$$

Where R_L, R_A, and R_O^T are the rotation matrices for look angle, attitude and orbit respectively

Rational function model rectification

The RFM sensor model describes the geometric relationship between the object space and image space. It relates object point coordinates (X,Y,Z) to image pixel coordinates (r,c) or vice versa using 78 rational polynomial coefficients (RPCs). For the ground-to-image transformation, the defined ratios of polynomials have the following form

$$r_n = \frac{p_1(X_n, Y_n, Z_n)}{p_2(X_n, Y_n, Z_n)} = \frac{\sum\limits_{i=0}^{m1} \sum\limits_{j=0}^{m2} \sum\limits_{j=0}^{m3} a_{ijk} X_n^i Y_n^j Z_n^k}{\sum\limits_{i=0}^{n1} \sum\limits_{j=0}^{n2} \sum\limits_{j=0}^{n3} b_{ijk} X_n^i Y_n^j Z_n^k} \qquad (7)$$

$$c_n = \frac{p_3(X_n, Y_n, Z_n)}{p_4(X_n, Y_n, Z_n)} = \frac{\sum\limits_{i=0}^{m1} \sum\limits_{j=0}^{m2} \sum\limits_{j=0}^{m3} c_{ijk} X_n^i Y_n^j Z_n^k}{\sum\limits_{i=0}^{n1} \sum\limits_{j=0}^{n2} \sum\limits_{j=0}^{n3} d_{ijk} X_n^i Y_n^j Z_n^k}. \qquad (8)$$

Where (r_n, c_n) are the normalized row (line) and column (sample) index of pixels in image space; X_n, Y_n, and Z_n are normalized coordinate values of object points in ground space; and the polynomial coefficients a_{ijk}, b_{ijk}, c_{ijk}, d_{ijk} are called Rational Function Coefficients (RFCs).

Orthorectification reprojection

Orthorectification algorithms are often performed in conjunction with re-projection procedure, where rays from the image are re-projected onto a model of the terrain. Fundamentally re-projection can be done in two ways:

- Forward projection or direct projection
- Backward projection or indirect method

In the first case of forward projection, the pixels from the original image are projected on top of the DEM of the 3D model and the pixels' object space coordinates are calculated. Then, the object space points are projected into the orthoimage

In the case of backward projection, the object space X, Y coordinates related to every pixel of the final orthoimage are determined. The height Z at a specific X, Y point is calculated from the DEM or the 3D model and then the X, Y, Z object space coordinates are projected in the original image in order to acquire the gray level value for the orthoimage pixel.
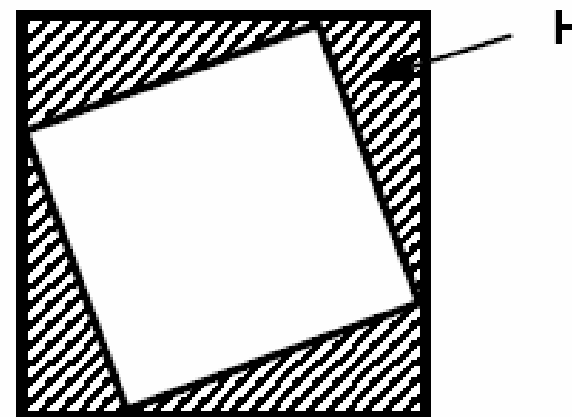
Input Image in scan, pixel reference

Output orthoimage with ground reference
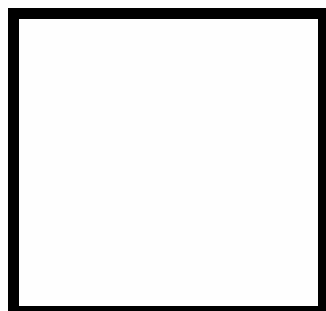
direct method
(transformation T)

indirect method
(inverse transformation T^{-1})

H

H ...Grey value of background (user defined, or fixed in programme)

In geometric transformations with grey level interpolation the indirect method is almost always used

Orthorectification process of remote sensed Image data
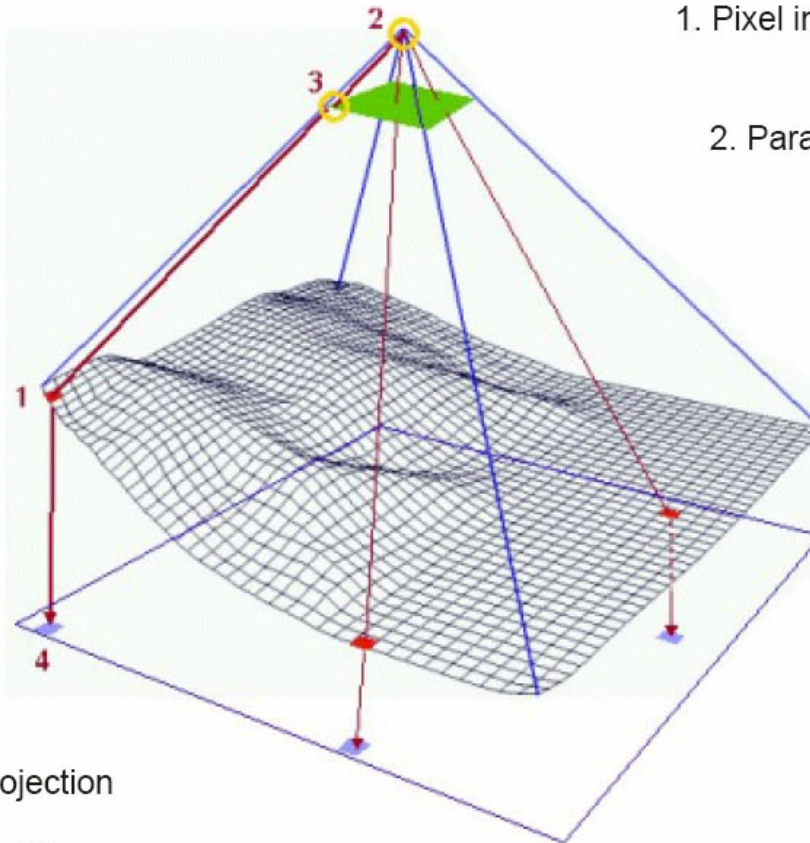
1. Pixel in the DEM (Height)

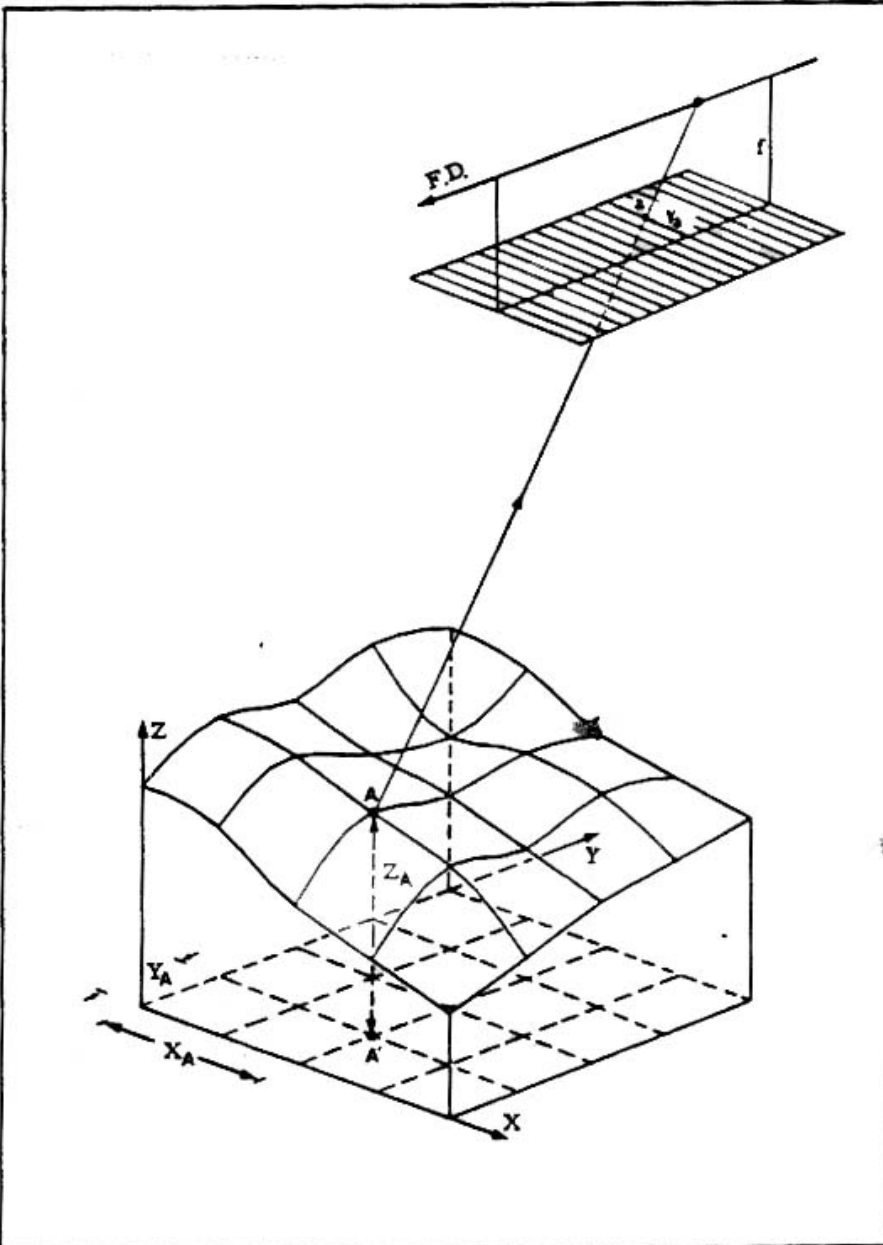2. Parameters in the Exterior Orientation

3. In the image, a Brightness Value is determined based on the resampling of surrounding pixels

4. Height, Exterior Orientation information and Brightness Value used to calculate equivalent location in the orthoimage

Orthographic Projection

www.satimagingcorp.com

Referring to fig. The ground co-ordinates (X,Y,Z) for ground point A are known. The location of the point on the orthoimage is 'A' and the corresponding point on the raw image is "a", that is the co-ordinate along the flight direction F.D. Then the sample number, that is the across-track coordinate is calculated. The determination of the line number is equivalent to determining the sampling time for point "a".

A schematic illustration of ground to image mapping for orthoimage generation

With non area sensors (e.g. linear CCDs) the respective geometric sensor models are used

• With satellite imagery the geometric transformation is often approximated by polynomials -> 3-D to 2-D transformation or physical sensor models

• Orthoimage grid spacing is usually smaller than the DTM spacing. Two options exist:

   - DTM densified by bilinear interpolation, then all orthoimage grid points transformed in pixel coordinate system
   - DTM points treated as anchor points and transformed in pixel coordinate system. The remaining orthoimage grid points get pixel coordinates through bilinear interpolation using the known pixel coordinates of the DTM points

Anchor point method is faster and results in similar accuracy.
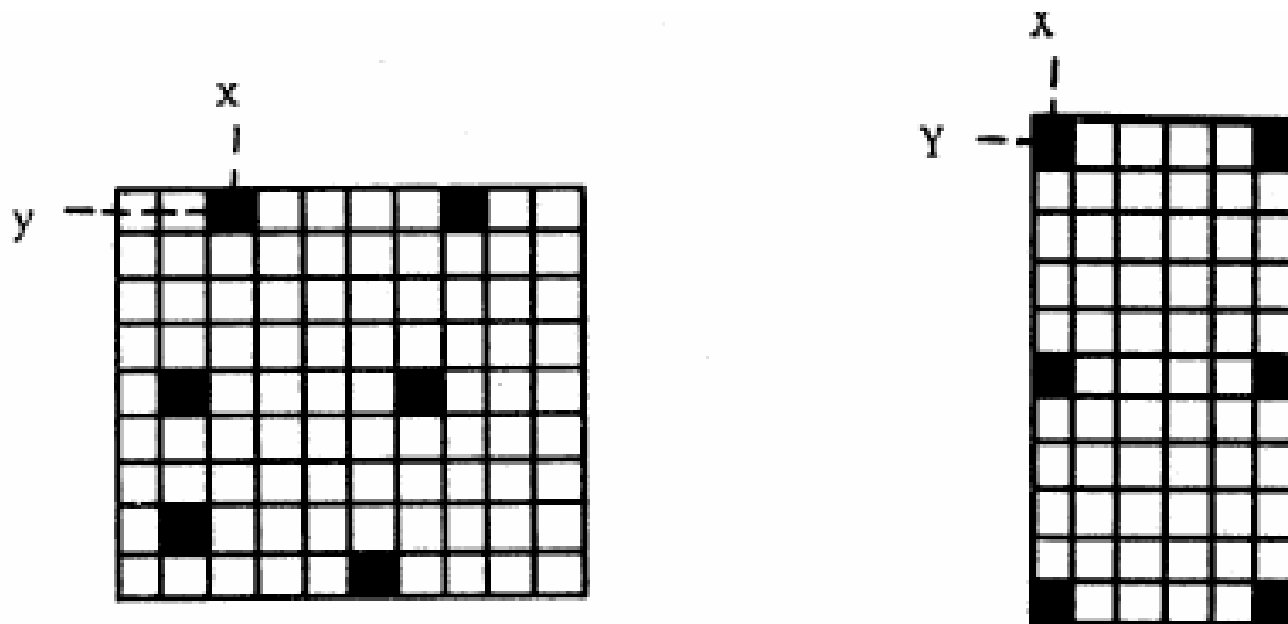
Left: digital input image ; right: orthoimage. Black squares represent anchor point locations. Note that the regular grid on object space is distorted in image plane. All white squares represent orthoimage grid points whose pixel coordinates are interpolated using the known pixel coordinates of the anchor points.

- **Planimetric accuracy of the orthoimage**

- under good conditions -> less than 1 pixel

-important influence factors:

- -DTM errors (especially at the image borders, variance in terrain relief) and density,
- -control point quality and distribution
- -Rectification procedures, e.g. by resection or bundle block adjustment
- -Geometric scanner errors and/or the occlusions in the image (especially in space imagery)
- -Final pixel size (expressed in ground units)

- **Non-DTM objects (buildings, bridges, trees etc.)**

- - are radially displaced in orthoimages
- -can be corrected a posteriori, or combination of DTM with 3-D description of the visible surface of these objects and then orthoimage generation
- -reduction of radial displacement by creating orthoimage only in the central image part

Planimetric Accuracy Control of Orthoimages

- **Use of well defined control points. Possible control sources:**
  - **- maps and large scale plans**
  - **- GPS**
  - **- photogrammetric determination using stereo pair**
  - **- derivation of control points using ortherectified stereo pairs**
  - **- use of existing higher accuracy orthoimages**
- **Control should cover whole image format and all existing terrain types**
- **If orthoimage produced using a DTM (not DSM), control must lie on the ground**
- **Analysis of the residuals and plot can reveal systematic errors (e.g. in sensor orientation)**
- **Overlay of raster map layers or vectors (especially roads) on the orthoimage**

Orthorectification of Satellite imagery - Work flow
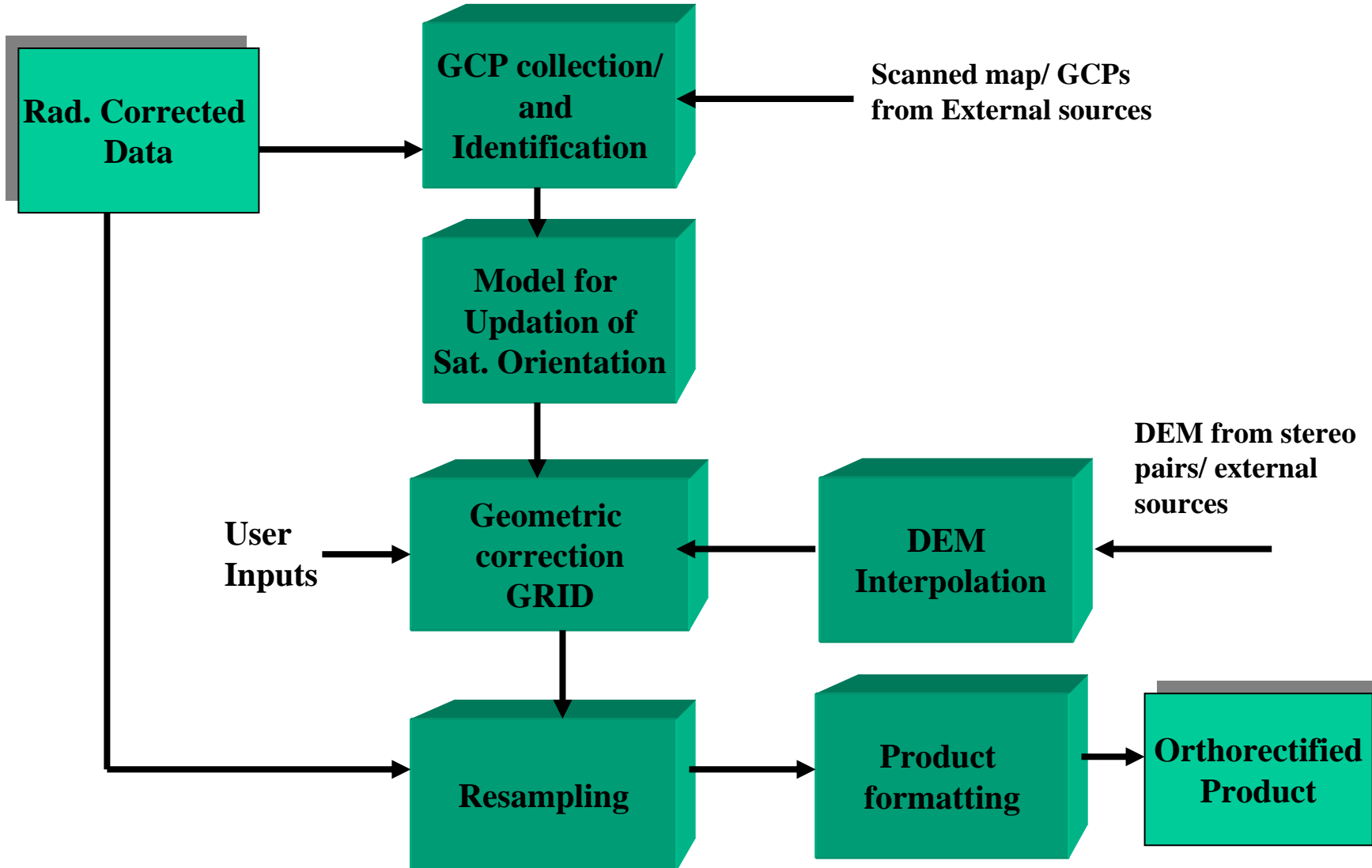
© DLR / ISTAR

Raw imagery

True Orthoimage, 25cm

High Resolution Stereo Camera (HRSC) Imagery

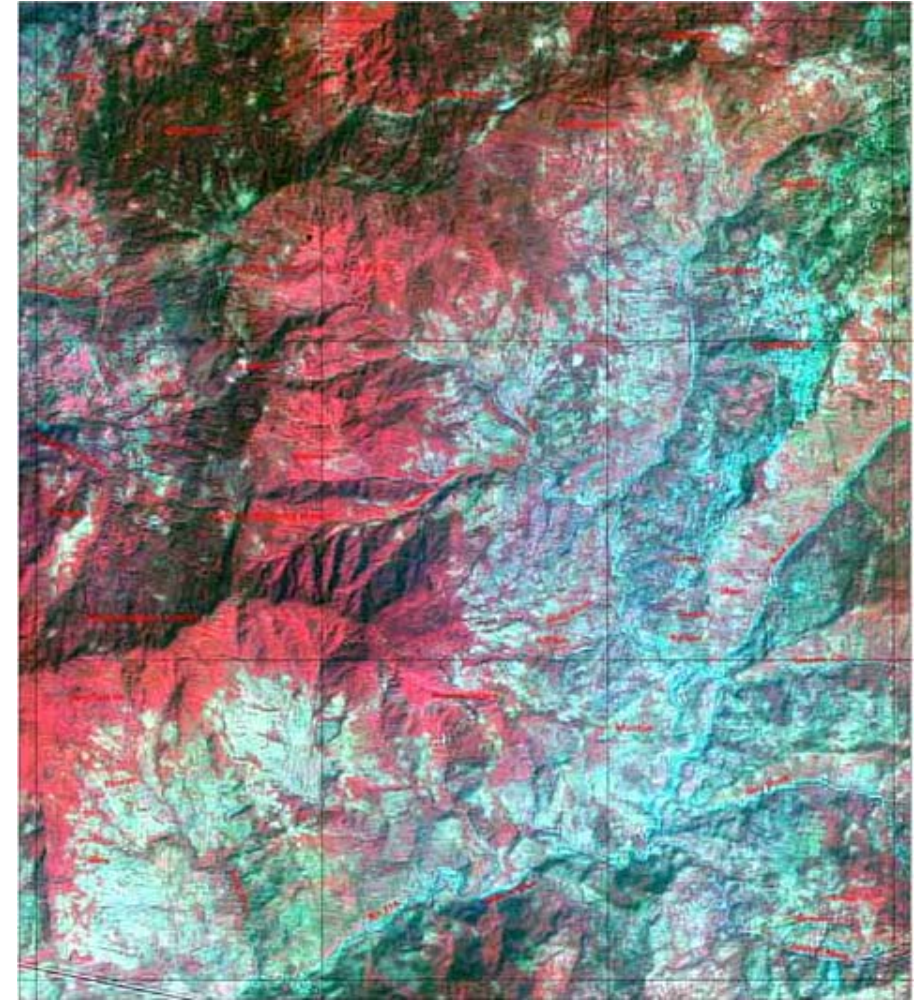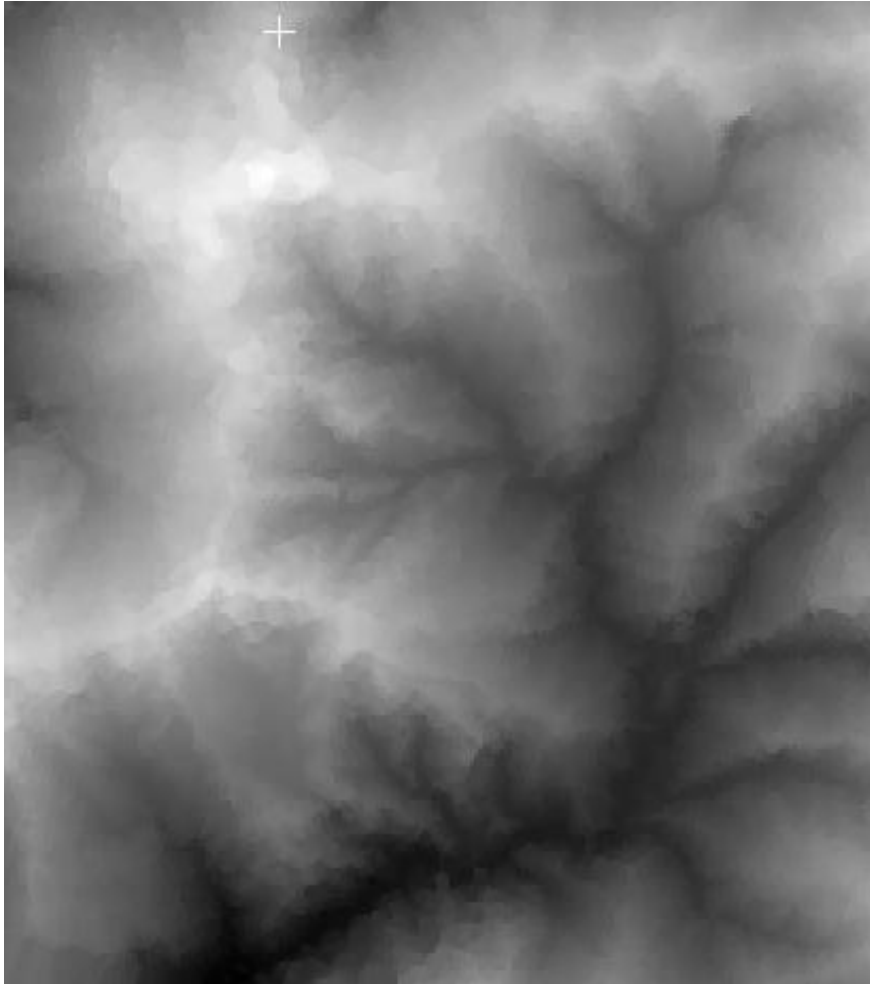**Quickbird Imagery Before & After Orthorectification**
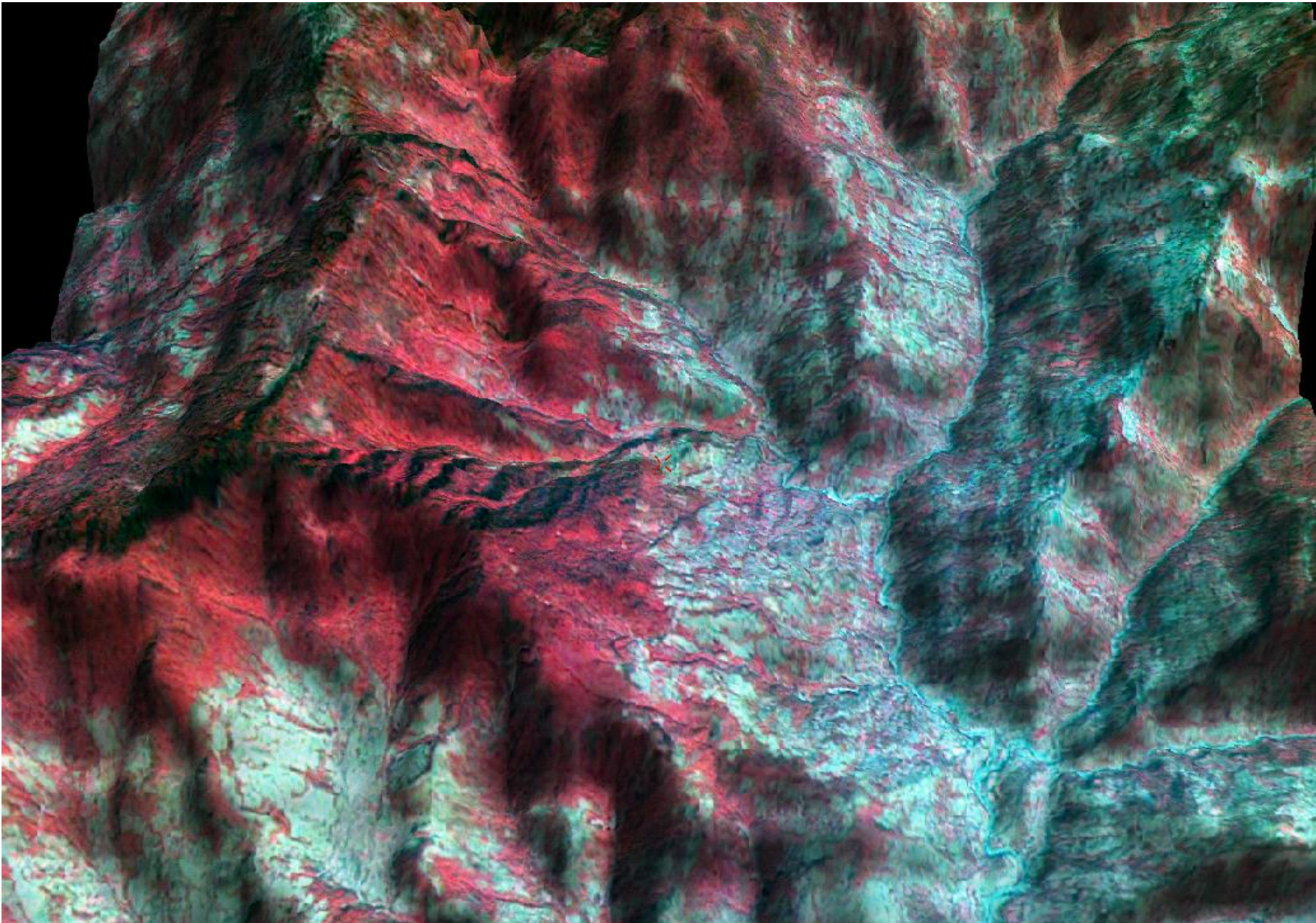
ORTHO IMAGE   GEOCODED IMAGE

The Shiwalik hills in Dehradun (India) is a highly undulated terrain with heights varying from 400m to 1400m.The generated Orthoimage has been overlayed with the survey of India toposheet.

(DEM in Image form with 62.5 m grid interval along with the orthoimage)

Elevation range: 500 m -   5000 m

Planimetric accuracy: <10 m in both X & Y

Area-1: Images from Cartosat-1

**Geometrically RAW Image
(Barcelona Area)**

Orthoimage (Barcelona Area)

Area-1: Images from Cartosat-1

Geometrically RAW Image (Barcelona Area)

OrthoImage (Barcelona Area)

Geometrically RAW Image

Orthoimage

Area-3: Images from Cartosat-1

Geometrically RAW Image   **Orthoimage**

Accuracy of DEM and Orthoimages of Cartosat-1

Case	Error Standard Deviation (in m)			Number of GCPs used for model/ evaluation/undulation
	Lat	long	height	
Area - 2	1.4	6.1	3.7	6/5 (400 m – 700m)
Area – 3	6.5	5.7	6.3	6/8 (500 m – 1000 m)
Area - 4	3.7	9.9	5.4	8/6 (500m – 2000m)

Quality of GCPs: medium to good

Accuracy of GCPs: 1 m – 2 m

Thank You