MODULE 2
Principles of Remote Sensing, Sensors and Platforms

Concepts of Cartography for Remote Sensing

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International e-learning course on
Introduction to Remote Sensing
Technology for Educators

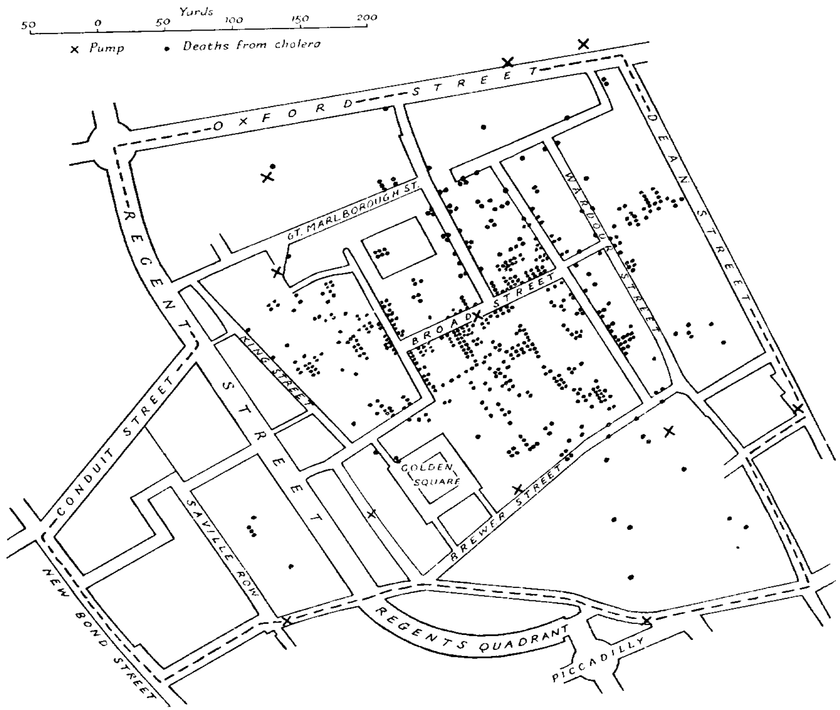
CEOS
Committee on Earth Observation Satellites

Summary

- Concepts of Geodesy
- Coordinate Systems
  - Map projections
  - Geometric transformations
- Integration with Remote Sensing
  - Geometric correction
  - Orthorectification

Introduction

London … 1854



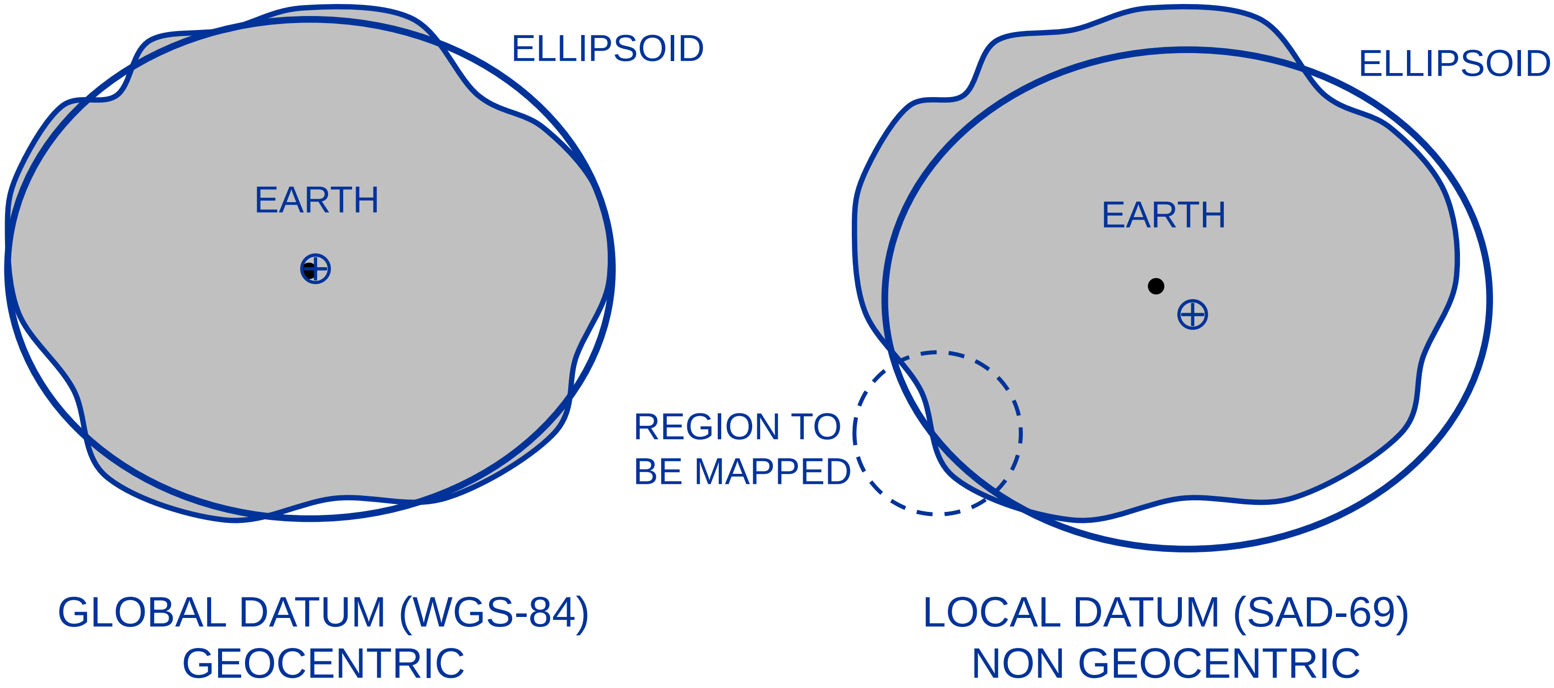
Concepts of Geodesy

- Shape and dimensions of the Earth
- Geoid
  - Earth’s gravity field
  - Earth’s mean sea level
- Cartographic Earth
  - Reference ellipsoid
  - Sphere

Concepts of Geodesy

- Horizontal or planimetric datum
  - Reference surface tied to the Earth's real surface
  - Global versus local datum
  - Geodetic coordinates change with the planimetric datum
- What is the meaning of 'geodetic coordinates'?
  - Geodetic x geographic

Concepts of Geodesy



Concepts of Geodesy

Geodetic latitude

Angle between the vertical (normal) to the reference surface (ellipsoid or sphere) at a given point and the equator

Geodetic longitude

Angle between the meridian at a given point and the reference (origin) meridian (Greenwich, by convention)

Concepts of Geodesy

SIRGAS-2000

- Current planimetric datum for Brazil (and Americas)
- 6,378,137 m of semi-major ellipsoidal axis
- 1/298,257222 of ellipsoidal flattening

SAD-69

- Old (?) planimetric datum for Brazil
- 6,378,160 m of semi-major ellipsoidal axis
- 1/298,25 of ellipsoidal flattening

<u>In practice, they both exist in Brazil!</u>

Concepts of Geodesy

Local planimetric datum

- SAD-69, NAD-27, Indian

Global planimetric datum

- WGS-84, SIRGAS-2000, NAD-83

Geographic coordinates, actually, geodetic coordinates, vary…

- Typically, from 40 m to 100 m between any local datum and WGS-84

With respect to the concept of planimetric datum:

Remember that changes in geographic coordinates do affect the accuracy of your GIS database

Understand the setup options of your GPS device

Be careful when importing or exporting data

Remember that SIRGAS-2000 = WGS-84 for any practical purpose in Remote Sensing and GIS

Concepts of Geodesy

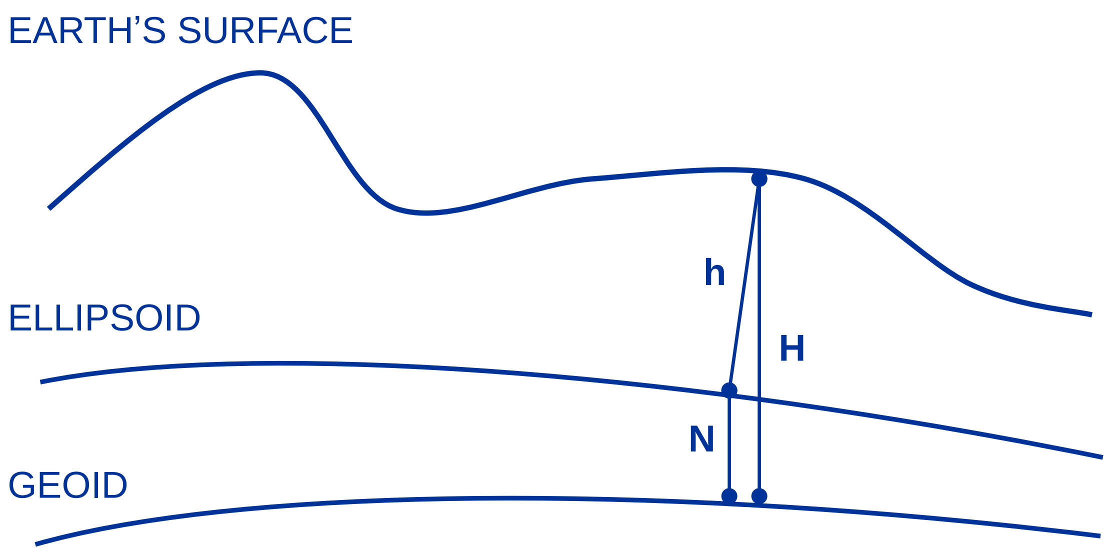
Vertical or altimetric datum

Reference surface for heigths

Continuous tide gauge measurements for determining the mean sea level

One of the tide gauges (in case there is a network) is adopted as reference for the vertical datum

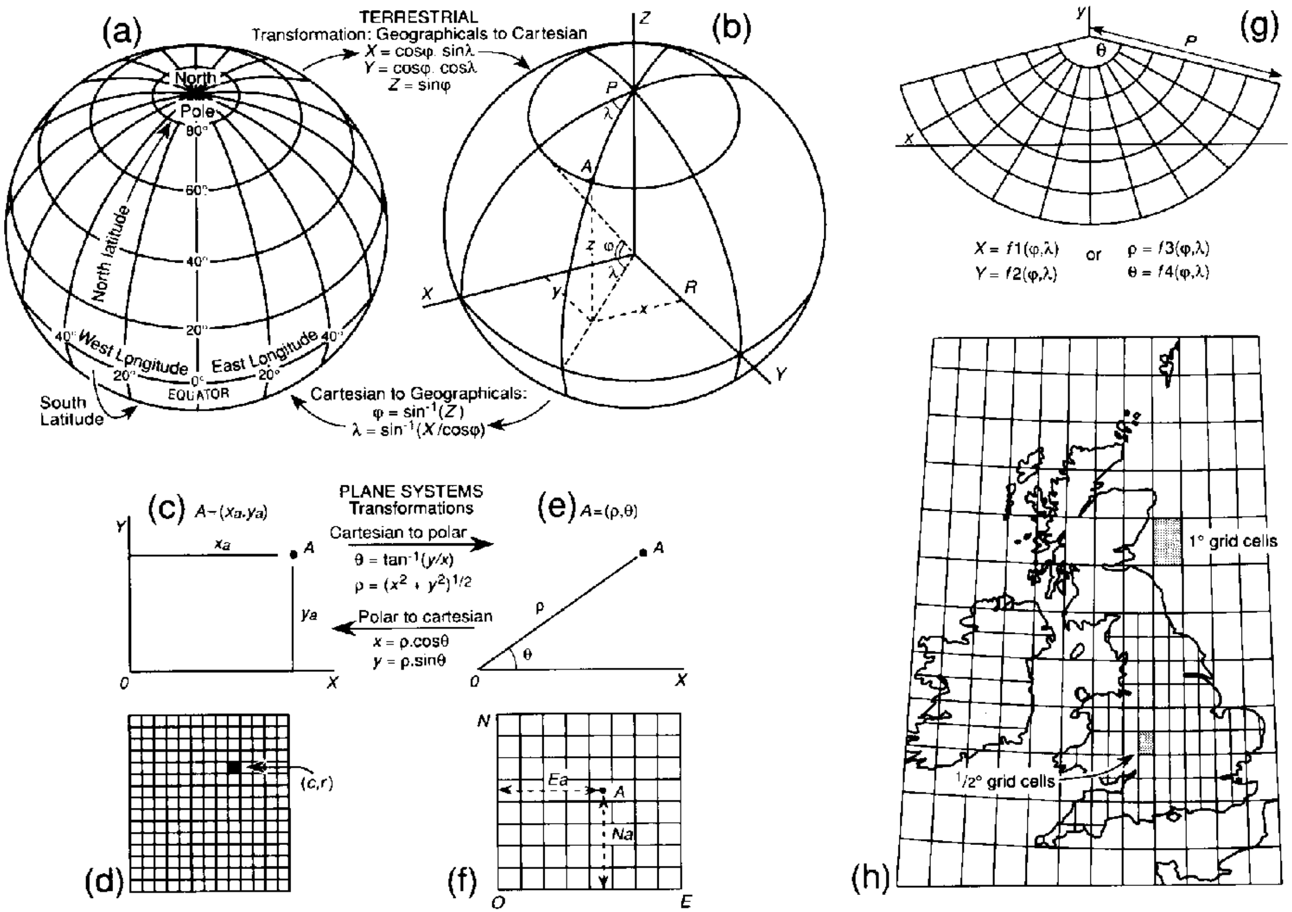
Concepts of Geodesy



H: ORTHOMETRIC HEIGHT... VERTICAL NETWORK (MAPS)
h: GEOMETRIC HEIGHT .... GPS MEASUREMENTS
N: GEOIDAL ONDULATION

$\therefore\ H \cong h + N$

Coordinate Systems



(source: Maguire, Goodchild, Rhind, 1991)

Coordinate Systems

Geodetic coordinates (geographic)

Reference surface: ellipsoid or sphere

Terrestrial geocentric coordinates (sphere)

$X = R.\cos\varphi.\cos\lambda$ $\varphi = \text{arcsen}(Z/R)$

$Y = R.\cos\varphi.\text{sen}\lambda$ $\lambda = \text{arctg}(Y/X)$

$Z = R.\text{sen}\varphi$

Coordinate Systems

Polar coordinates

Used for developing conical map projections

Cartesian coordinates

Map projection coordinates

$x = \rho \cos\theta \qquad \theta = \text{arctg}\,(y/x)$

$y = \rho \,\text{sen}\theta \qquad \rho = (x^2 + y^2)^{0.5}$

Map Projections

Projection systems – analytical development

$x = f_1(\lambda,\varphi)$ $y = f_2(\lambda,\varphi)$

$\lambda = g_1(x,y)$ $\varphi = g_2(x,y)$

Properties

Conformal or orthomorphic projections

Local angles are shown correctly on the map (shapes as well)

Equal-area or equivalent projections

Areas measured on the map are preserved

Map Projections

Reference surface

- Sphere, ellipsoid

Projection surface

- Plane, cone, cylinder, polyhedron

Relative position of projection surface

- Normal or equatorial, oblique, transverse

Projection construction method

- Conventional, projective, analytical

Map Projections

Land- und Himmelscharten.

$$+M\cos. p = n$$
$$-N\cos. p = m$$

ausführlich vorgestellt werden. In Ansehung der erstern ist nach angestellter Rechnung und behöriger Reduction

$$
\begin{array}{llll}
M\cos. p & & & \\
= \frac{1}{2}A' & + \frac{1}{2}B'\lambda & + \&c. \\
+ \frac{1}{2}(2A'')\cos. p & + \frac{1}{2}.\, 2B''\cos. p\,\lambda & + \&c. \\
+ \frac{1}{2}(A' + 3A''')\cos. 2p & + \frac{1}{2}(B' + 3B''')\cos. 2p.\lambda & + \&c. \\
+ \frac{1}{2}(2A'' + 4A'''')\cos. 3p & + \frac{1}{2}(2B'' + 4B'''')\cos. 3p.\lambda & + \&c. \\
+ \frac{1}{2}(3A''' + 5A^{v})\cos. 4p & + \frac{1}{2}(3B''' + 5B^{v})\cos. 4p.\lambda & + \&c. \\
\quad \&c. & & \\
\end{array}
$$

und

$$
\begin{array}{lllll}
n = & b & + 2c\lambda & + 3d\lambda^2 & + \&c. \\
& + b'\cos. p & + 2c'\cos. p\,\lambda & + 3d'\cos. p.\lambda^2 & \\
& + b''\cos. 2p & + 2c''\cos. 2p.\lambda & + 3d''\cos. 2p.\lambda^2 & \\
& + b'''\cos. 3p & + 2c'''\cos. 3p.\lambda & + 3d''\cos. 3p.\lambda^2 & \\
\end{array}
$$

§. 76.

Hier können nun die Coefficienten Glied für Glied mit einander verglichen werden; und so findet man

$$
\begin{array}{l|l|l}
b = \frac{1}{2}A' & c = \frac{1}{4}B' & d = \frac{1}{6}.C' \\
b' = \frac{1}{2}(2A'') & c' = \frac{1}{4}(2B'') & d' = \frac{1}{6}(2C'') \\
b'' = \frac{1}{2}(A' + 3A''') & c'' = \frac{1}{4}(B' + 3B''') & d'' = \frac{1}{6}(C' + 3C''') \\
\end{array}
$$

(source: Johann Heinrich Lambert, 1772)

Map Projections

Plane or azimuthal projections

- Tangent or secant plane
  - Polar stereographic, Lambert azimuthal

Conical projections

- Tangent or secant cone
  - Lambert conical, Albers conical

Cylindrical projections

- Tangent or secant cylinder
  - UTM, Mercator, Miller

Map Projections Parameters

Cartographic Earth (ellipsoid or sphere)

- Planimetric datum

Standard parallels

- Loci of no deformation

Origin longitude (central meridian)

- Plane coordinates – Y axis

Origin latitude

- Plane coordinates – X axis

Origin offsets – X and Y

Main Map Projections

- UTM (“Universal Transverse Mercator”)
  - Topographic maps
- Mercator
  - Nautical charts
- Lambert conformal conical
  - Topographic and smaller scale maps
  - Aeronautical charts
- Polyconic
  - Thematic maps

Other Map Projections

- Cylindrical equidistant
  - Fast display in GIS
  - World maps
- Polar stereographic
  - Replaces UTM for mapping polar regions
- Bipolar oblique conical conformal
  - Map of the Americas (North, Central, South)
- Albers conical equal-area
  - Area measurement in GIS

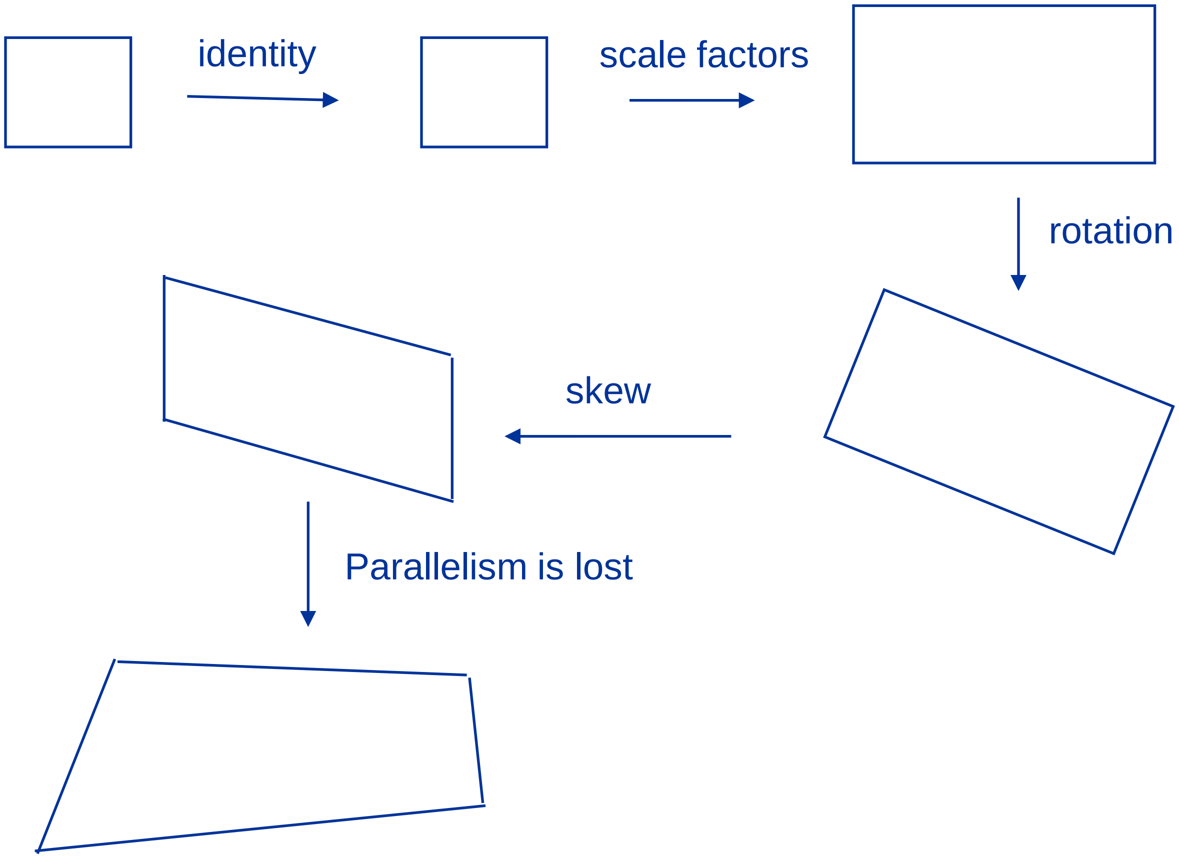
Geometric Transformations

Importance for Remote Sensing and GIS

- Relations among different coordinate systems
- Image registration
- Refinement of geometric correction methods
- Georeferencing of vector data

Basic geometric support to mathematical modeling in GIS

Geometric Transformations



Geometric Transformations

Orthogonal - 3 parameters

1 rotation, 2 displacements

Similarity - 4 parameters

1 rotation, 1 scale factor, 2 displacements

Affine orthogonal - 5 parameters

1 rotation, 2 scale factors, 2 displacements

Affine - 6 parameters

1 rotation, 1 skew, 2 scale factors, 2 displacements

Polynomial and projective - $\geq$ 6 parameters

Integration with Remote Sensing

The practical use of Remote Sensing images requires integration with other data sources

Integration of satellite imagery into a GIS database is accomplished by a procedure named <u>geometric correction</u>

Geometric Correction

Importance

- Removal of systematic distortions
- Multi-temporal studies
- Data integration in GIS

Requirements

- Knowledge of existing distortions
- Selection of suitable mathematical model
- Assessment and validation of results

Geometric Correction

Sources of geometric distortion (optical EO missions)

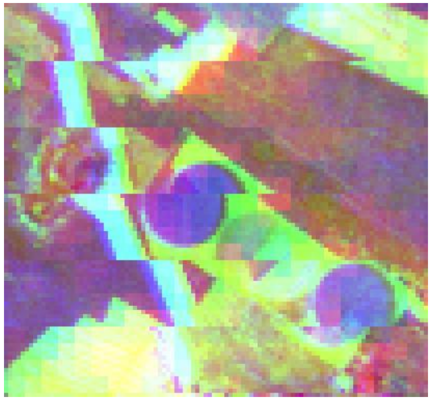
Earth rotation (skew)

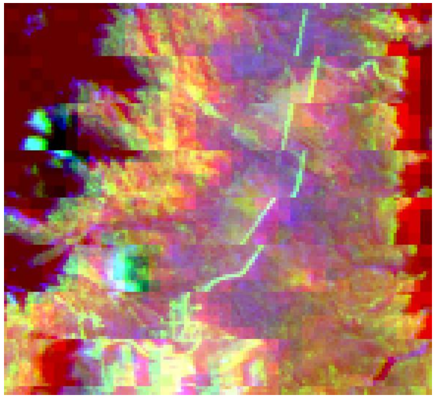
Panoramic distortions (compression)

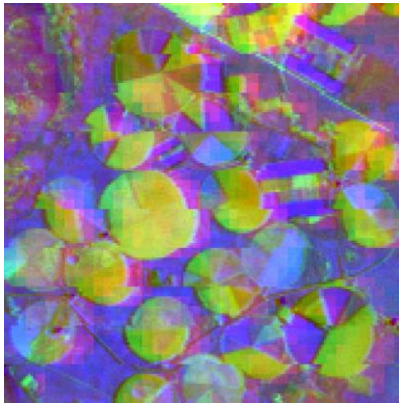
Earth curvature (compression)

Changes in altitude, attitude and velocity of the satellite

Geometric Correction - Distortions







Geometric Correction

Geometric (direct) transformation (T)

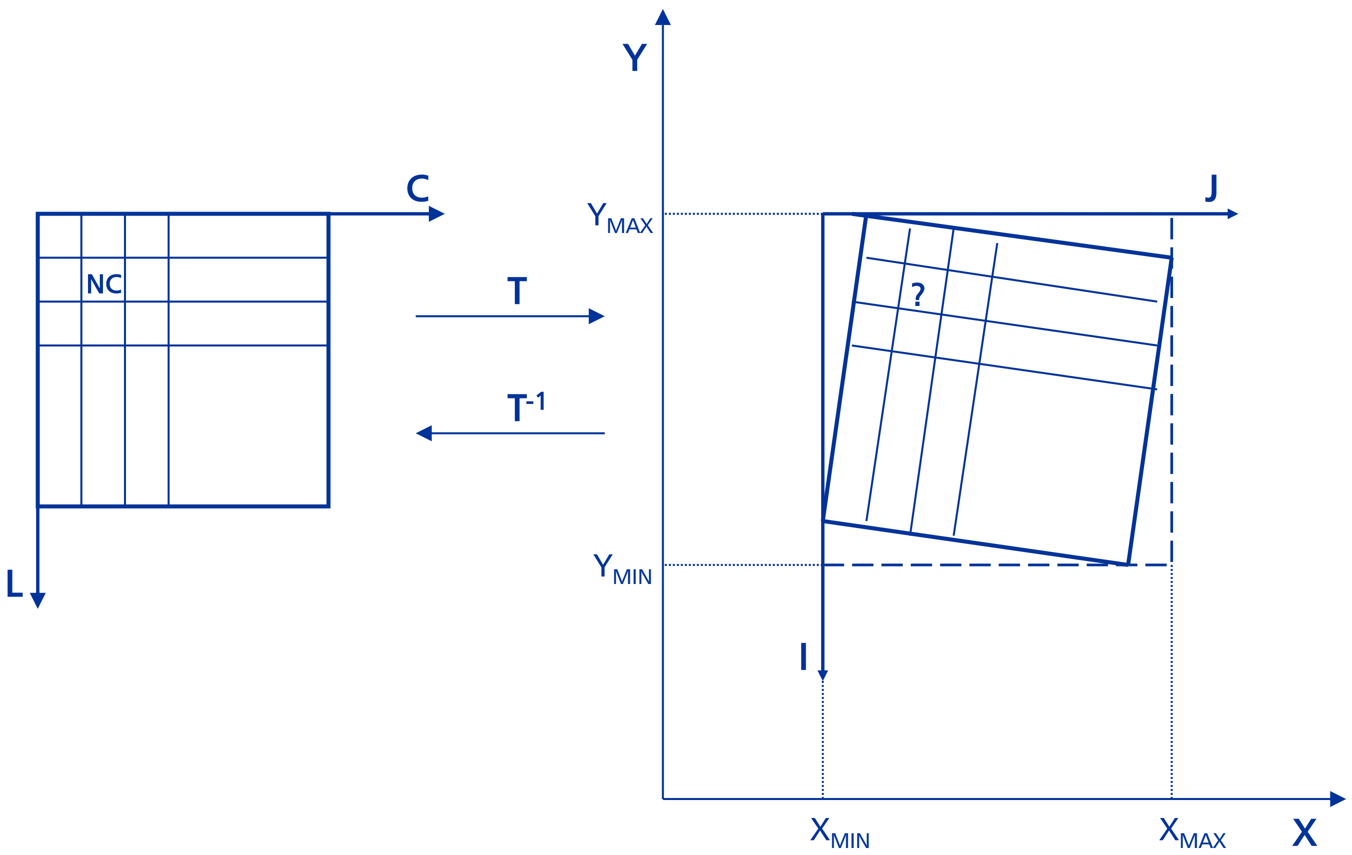
- Photogrammetric model
- Orthorectification
- Polynomial model (image registration)

Inverse transformation (T^{-1})

Resampling (interpolation)

- Nearest neighbor
- Bilinear
- Cubic convolution

Direct and Inverse Transformations



Photogrammetric Model

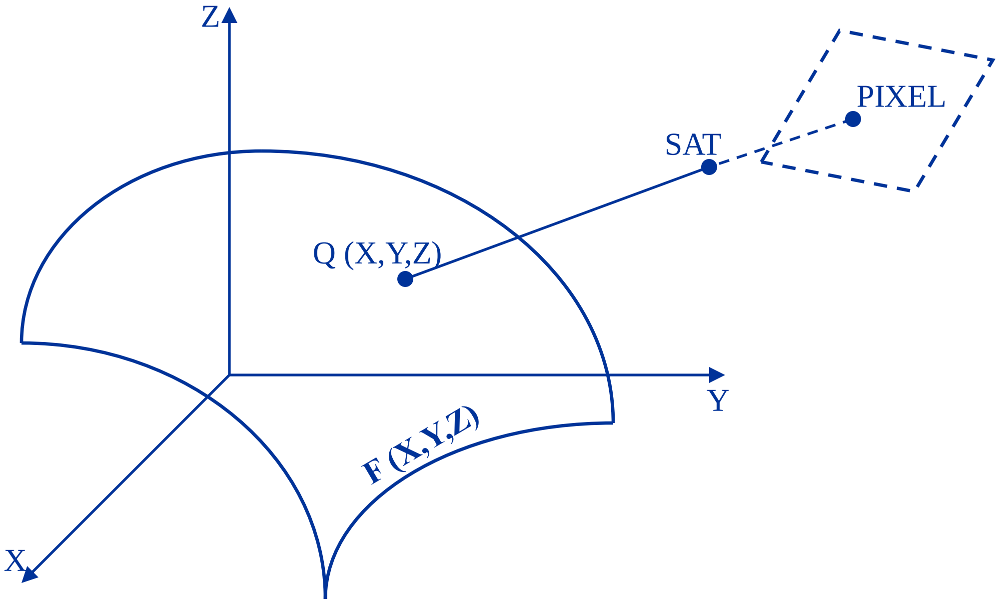
Establishes the relation between one pixel on the raw image with the corresponding point on the Earth's surface expressed by Cartesian terrestrial geocentric coordinates

Addresses the physical concept of image acquisition and attempts to model all distortions globally

Model implemented in ground stations to generate products – too complex for end users

Photogrammetric Model

The satellite position and the viewing direction define a straight line that intersects the Earth's surface



Photogrammetric Model

- Satellite orbit parameters
  - Ephemeris and attitude data
- Parameters related to each camera or instrument
  - Viewing vector or direction
  - Sweeping frequency or sampling rate
  - Orientation between camera reference system and attitude reference system (bore sight angles)
- Earth reference surface
  - Semi-major axis and flattening

Image Registration

Makes use of simple geometric transformations to map images onto a GIS database reference system

Transformation parameters are computed through the measurement of coordinates of control points

The number and the distribution of control points determine the accuracy of the image registration process

Image Registration

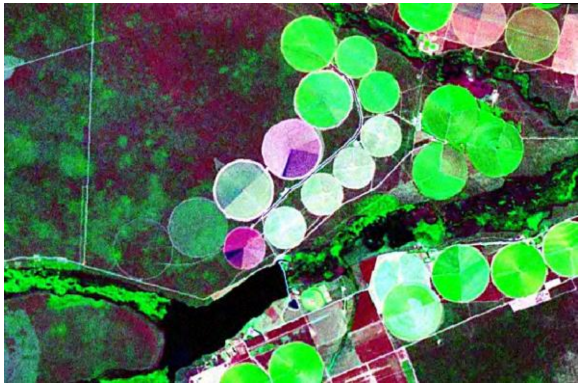
Advantages

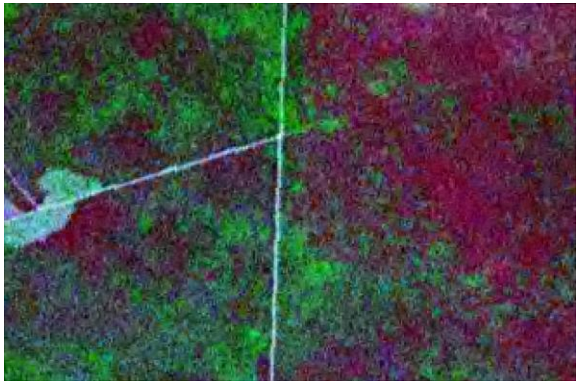
- Simplicity – really meant for end users
- Does not require previous knowledge of parameters related to satellite orbit or camera imaging mode

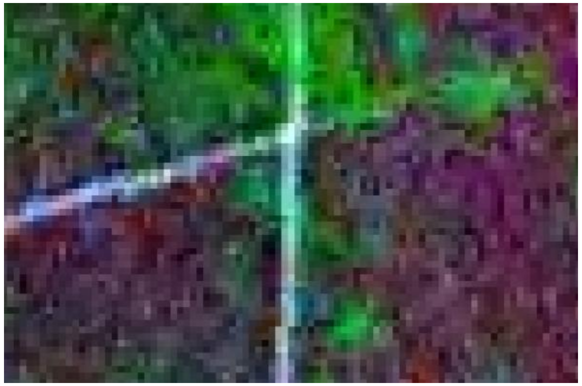
Disadvantages

- Does not model high frequency distortions
- Requires a minimum number of well defined control points
- Does not consider the physical concepts involved in satellite image acquisition

Image Registration – Control Point







Orthorectification

Classical Photogrammetry

- Rectification is the process of correcting off-nadir aerial photographs in order to account for existing relief (topography)
- Rectified aerial photographs are 'equivalent' to vertical aerial photographs but they shown objects as they were captured in off-nadir photographs

Remote Sensing images

- Photogrammetric model is applied over a digital elevation model to produce terrain-corrected images
- Approximate models available in commercial and open source software make use of Rational Polynomial Coefficients (RPC) for ease of implementation

Orthorectification

Planimetric displacement due to relief as a function of the viewing direction (angle)

Viewing angle (º) Altitude (m)	0.0	4.5	9.0	13.5	18.0	22.5	27.0
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
500	0.0	44.5	89.8	136.7	186.3	239.7	298.7
1000	0.0	89.0	179.5	273.4	372.5	479.4	597.3
1500	0.0	133.4	269.3	410.0	558.7	719.0	895.9
2000	0.0	177.9	359.0	546.6	744.8	958.6	1,194.5
2500	0.0	222.4	448.7	683.2	931.0	1,198.1	1,492.9
3000	0.0	266.8	538.4	819.8	1,117.1	1,437.6	1,791.3

Orthorectification

Rational Polynomial Coefficients

- Set of coefficients provided together with satellite images to allow end users to 'generate' an approximate generic orbit to orthorectify the images
- Coefficients can also be computed by using a set of control points (quantity and distribution are crucial)
- Coefficients are used to solve third order (degree) rational polynomials
- Solution available in most commercial and open source GIS

Rapid Positioning Capability

- Acronym used when the real orbit is replaced by the rational polynomial approach