Issues about Satellite Images Georeferencing in Argentina

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Key words: Remote sensing; satellite images; reference systems; plane coordinates.

SUMMARY

Geometric corrections are intended to minimize or eliminate the distortions that are present in the geometry of satellite images. Some distortions are minimized by reception stations, which offer different levels of correction.

The correction process can be approached by two different levels; by adjusting the image to a map or to another image already corrected, or by correcting the systematic distortions according to the orbital parameters of the satellite.

It has been recognized that the adjustment of an image to a map or to another image already corrected, is more rigorous. This adjustment is called georeferencing and it consists of a process of change of space of reference.

The conception of a reference system responds to a mathematical approach which has made it possible to establish models, parameters, and constants according to which, different coordinate systems derive. The reference frame derives from putting the reference system into practice, materializing networks of points on the land and determining its coordinates through a process that responds to the adopted model and that basically consists of integral design of the network, boundary points, measurement, calculation, and compensation.

The reference system which gives place to the reference frame, implies then, the consideration of the Earth as an ellipsoid - mathematical model that sets the parameters of the ellipsoid and establishes relationships between ellipsoid and geoid -, the definition of a projection system of the ellipsoid for its representation on the drawing - model intended to present the minimum deformations - and the definition of a system of plane coordinates associated to the projection.

The Argentine geodesic system, called Campo Inchauspe 69, is associated with an ellipsoid of regional reference whose size and shape coincides with the International ellipsoid of 1924. This system of local reference and not geocentric, began to be replaced by a unique reference system through the reference frame POSGAR'94 [Argentine Geodesic Positions] which materializes the reference system WGS 84.

This reference frame, integrated with SIRGAS [Geocentric Reference System for South America], has recently been calculated, adjusted with scientific software and supported with a network of superior order SIRGAS 95, appearing in this way the frame called POSGAR'98.

Therefore, in this paper, the implications that have for the georeferencing of satellite images the two reference systems that coexist in Argentina, one local and the other global, are going to be analyzed, keeping in both the same system of projection and coordinates Gauss-Krüger.

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1. INTRODUCTION

The distortions in satellite images are errors whose effects have to be corrected or minimized to do multispectral analysis; the distortions can be radiometric or geometric.
Radiometric distortions can be originated in the action the atmosphere produces in the radiance detected by the sensor, in the time of the year in which the image is detected, and in the defects this sensor may have.

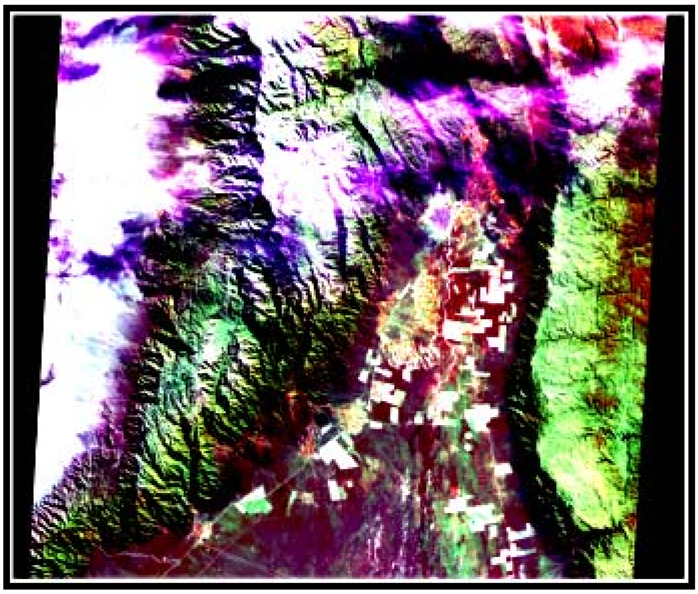
Geometric distortions, in general, are caused by the configuration of the satellite, the geometry view of the sensor and by the topography of the land observed.

Geometric corrections are intended to minimize or eliminate the distortions that are present in the geometry of images. The distortions which are originated in the same capture system, as the panoramic distortion, distortion by transverse inclination, longitudinal inclination, turn, translations and change in the orbital height of the sensor, as well as the distortions caused by the Earth curvature, are generally minimized by reception stations, offering different levels of correction.

The Earth curvature also causes alterations in the pixel size – which grows to the borders – emphasizing the panoramic distortions. The relief originates an apparent displacement of the points elevated in the land in its corresponding image point. This displacement depends on the parameters as the localization and the position of the image, the elevation of the point in the land and others which are specific of the kind of sensor. In addition, the Earth rotation originates a displacement in the detection area due to the time that the sensor takes to capture the complete scene, which together with the satellite orbit inclination, produces images with a rhombus shape with NE-SE orientation.

The geometric corrections of the images are indispensable to compensate the variations resulting from different dates of scenes' acquisition (detection of changes), to create mosaics (set of two or more images) and fundamentally, for cartographic applications.
The correction process can be approached by two different levels (Pinilla, 1995); by adjusting the image to a map or to another image already corrected, or by correcting the systematic distortions according to the orbital parameters of the satellite, through the application of mathematical models. For that reason, some authors distinguish between parametric and non-parametric corrections. In spite of this, the adjustment of an image to a map or to another image already corrected is considered to be more rigorous.

Illustration 1: Displacement in the detection area of Landsat TM full scene –latitude 28°S-



2. GEOREFERENCING

The most rigorous geometric correction is called georeferencing because it consists of a process of change of space of reference: the original image taken by the sensor is defined in a local system where the location of each pixel is determined by its situation in rows and columns, forming the space image. Georeferencing adjusts this image to a new space of reference where each pixel has its equivalent value XY in a determined cartographic projection system, establishing in this way the space projection.

Georeference means *"to attribute spatial coordinates to each point of the land,... the objects turn in this way georeferenced and it is possible to relate them spatially and correlate phenomena that until now were objects of different disciplines"* (Usandivaras and Brunini, 1997). In consequence, the concept of georeferencing of satellite images involves establishing relationships between each point of the land and its corresponding representation in the image through the assignment of coordinates linked to the land and related to a spatial reference system.

The reference systems have traditionally been classified as relative or absolute, according to the localization of the geometric entities in relation to other entities independently of the absolute position in the three-dimensional space, or according to the localization of each entity in relation to other entities in a unique and universal way in the space.

From the point of view of the satellite images georeferencing, it is intended that the reference system used responds to this last criterion, i.e. it has to be unique, in order to obtain the best use of the different applications through the integration of results in systems of geographic or territorial information which require a great volume of updated and precise information about multiple aspects related to the land, especially about natural resources and the environment, to satisfy the increasing demand of numerous users.

It has been pointed out that the conception of a reference system responds to a mathematical approach which has made it possible to establish models, parameters, and constants according to which different systems with coordinates of points without errors derive. In addition, these systems admit transformations between one system and the other (Haar, 1996). He affirms that the reference frame arises from applying the reference system, i.e. materializing networks of points on the land and determining its coordinates through a process that responds to the adopted model and that basically consists of integral design of the network, boundary points, measurement, calculation and compensation.

The materialized points in the land, whose coordinates have been determined by application of the reference system, as they are regularly distributed in a country, not only provide the bases for the cartographic representation of the land, but also they are used to link different kinds of surveying through spatial reference. This spatial reference is carried out in relation to one or more points of the basic network to serve as a support.

The reference system which gives place to the reference frame, implies then, the consideration of the Earth as an ellipsoid – mathematical model that sets the parameters of the ellipsoid and establishes relationships between ellipsoid and geoid –, the definition of a projection system of the ellipsoid for its representation on the drawing – model intended to present the minimum deformations – and the definition of a system of plane coordinates associated to the projection.

The most common cartographic projection systems are cylindrical, conical and azimuthal. Cylindrical projections, for example, are characterized by the representation of parallels through straight horizontal lines, whose separation is not constant (it varies with latitude), meridians are represented by straight vertical lines equally spaced, and the Poles – in fact, they are points –, are represented by straight horizontal lines equal to the Equator. A variation of this kind of projection is the cylindrical transverse Mercator or cylindrical by Gauss, which locates the cylinder tangent to a meridian. In this way, the projected shapes in small areas through the central meridian are kept, minimizing the deformations.

Even though the definition of each ellipsoid has tried to achieve the objective of adjusting in the best way the real shapes and dimensions of the Earth given the characteristic problems of the lands of the different countries, there have arised regional or continental ellipsoids with origins generally that are generally displaced from the geocenter. In consequence, it can be noticed that each country has defined an independent reference system but also, as it responds to a determined ellipsoid model, it is possible to develop new models in order to substitute it for a superior one. As a result, a wide list of different ellipsoids was made with ellipsoids that had been used since last century in the definition of reference systems, among them are, for instance, the International ellipsoids, South American 1969, GRS 1980, SGS 85 and WGS 84.

Each reference ellipsoid has associated with it a system of geodesic coordinates defined by latitude – angle that forms the normal latitude to the ellipsoid with the Equator –, longitude – angle between the local geodesic meridian and the meridian chosen as origin –, and vertical ellipsoidal heights.

3. ARGENTINE GEODESIC SYSTEM

The Argentine geodesic system, called Campo Inchauspe 69, is associated with an ellipsoid of regional reference whose size and shape coincides with the International ellipsoid of 1924 adjusting the origin and the spatial orientation so that it results tangent to the geoid in the Campo Inchauspe point – *datum* point–. The ellipsoid parameters are given by the semi-major axis a = 6,378,388 meters and the eccentricity $1/f$ = 297 (semi-minor axis b = 6,356,911.95 meters).

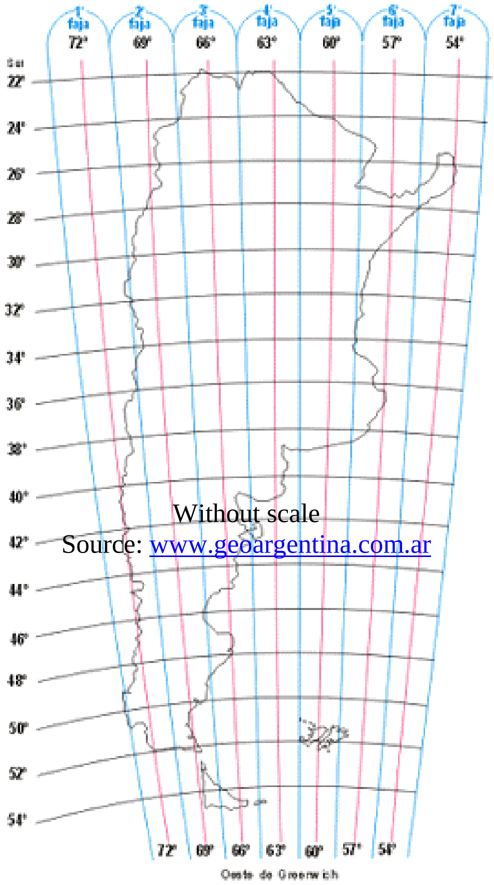
When relating the geodesic coordinates corresponding to different ellipsoids, there arises, from a perspective theory, the need to define the parameters that link both systems, taking into consideration the different shapes and sizes they represent, the displacement of the origin, the rotation axis and the scale factor that solve the transformation by the well-known Molodensky formulas. From the point of view of the practice, difficulties are significant because of the errors that affect the coordinates of both systems and that inevitably propagate to the transformation parameters and, also because of the consideration of ellipsoidal heights. The Argentine geodesic system, for instance, considers the orthometric height H – distance between the geoid and a point, measured along the plumb line –, and being the geodesic height h = H + N, where N is the undulation of the geoid with regard to the ellipsoid in the considered point, it is necessary to determine with precision, regional values of the geoid's undulation, whose resolution is not a geometrical problem but a physical one. This aspect and others have affected the will to analyse the convenience of replacing in our country, the reference frame Campo Inchauspe 69 by a satellite reference frame.

The practical difficulties of transforming coordinates of a system into another, the incorporation of GPS (Global Positioning System) and GIS (Geographic Information System) technologies and, the undeniable contribution of remote sensing to the knowledge of the planet, have emphasized the need of developing a unique reference system. Consequently, there has appeared the World Geodetic System named WGS 84 – system and ellipsoid –, adopted by GPS, pointing out that one of the most general applications of the global positioning system consists of the determination of coordinates of points in the land to georeference satellite images.

Ellipsoidal parameters are defined by a = 6,378,137.00 meters and $1/f$ = 298,257223563 (b = 6,356,752.31 meters), which compared to the ellipsoid associated to Campo Inchauspe 69 is WGS 84, an ellipsoid slightly smaller (shorter axis) and of different shape (different eccentricity).

Therefore, the materialization of the reference system provides the bases for the cartographic representation of the land and, as a consequence, there appears the interest of the kind of projection used to represent the ellipsoid in the drawing. On the other hand, the simplification of the geodesic coordinates latitude and longitude on the ellipsoid gave place to the overlapping of squares of rectangular plane coordinates on the topographic maps, developing particular systems according to the needs of the different countries. The UTM (Universal Transverse Mercator) system, for example, based in the transverse projection Mercator, defines columns between 84ºN and 80ºS latitudes that have 6º of longitude, called zones, with divisions in squares of 8º of latitude of height (Robinson, 1987). The origin of the coordinates has been set for each zone with a value of 500,000 for the central meridian and with an assignment for the Equator of 0 meter North for the Northern Hemisphere and 10,000,000 m North for the Southern Hemisphere.

Illustration 2: Division of the Argentine Republic in 7 meridian bands of cartographic projection



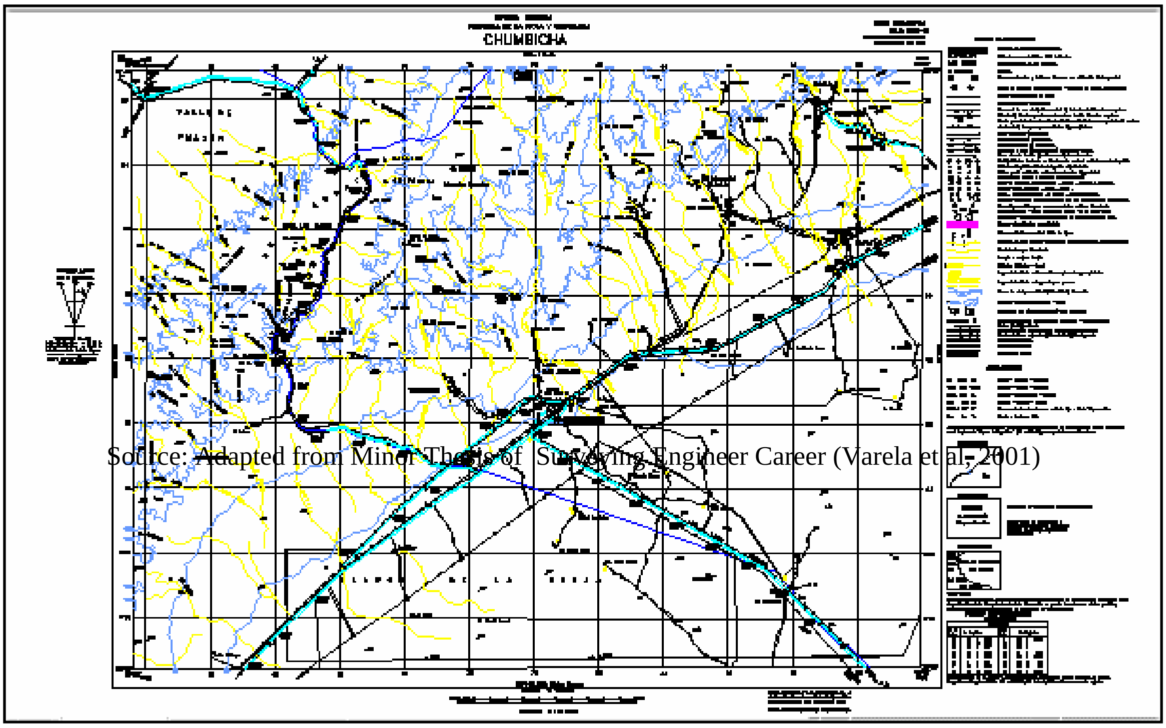
Without scale
Source: www.geoargentina.com.ar

The Gauss-Krüger system – projection and coordinates – used by the Argentine Geographic Military Institute to make topographic maps of the continental territory and Malvinas Islands, is based in transverse cylindrical projection, establishing 7 meridian bands of 3º of longitude wide and 34º long – latitude –, numbered from West to East, with origin of coordinates in the intersection of the South Pole with the central meridian of each band, assigning the value of 0 meter for the Southern Pole and 500,000 meters for the central meridian – preceded by the number of band –.

The local and non-geocentric reference system Campo Inchauspe 69, which had been adopted by Argentina, started to be replaced by a unique reference system through the reference frame POSGAR'94 (POsiciones Geodésicas ARgentinas) [Argentine Geodesic Positions] which materializes the reference system WGS 84, associated to the reference system SIRGAS (Sistema de Referencia Geocéntrico para América del Sur) [Geocentric Reference System for South America] and through this system, associated to the International Terrestrial Reference Frame (ITRF).

On the other hand, the reference frame POSGAR'94, integrated with SIRGAS, has recently been calculated, demonstrating that coordinates of the points of the network experimented slight variations. The coordinates that have arisen from the new calculation of the Argentine network, adjusted with scientific software and supported with a network of superior order SIRGAS 95, are part of the frame called POSGAR'98.

Illustration 3: Topographic Chart 2966-15 "Chumbicha" with plane coordinates Gauss-Krüger calculated from Inchauspe 69



Source: Adapted from Minor Thesis of Surveying Engineer Career (Varela et al, 2001)

Therefore, at present, there are two reference systems that coexist in Argentina, one local and the other global, which keep the same projection and coordinates Gauss-Krüger. Consequently, they have plane coordinates Gauss-Krüger calculated from Inchauspe 69 and plane coordinates Gauss-Krüger calculated from WGS 84.

4. SATELLITE IMAGES GEOREFERENCING

In order to georeference satellite images, it is necessary to select control points in the image to recognize them easily in the ground, in a chart or in other georeferenced images and, to establish the coordinates of the control points in a specific reference frame. Taking into account the control points, adjustment equations are calculated. These equations transform the image coordinates (row, column) into coordinates (x, y) of the selected reference system to make the resampling of the image to the new coordinates' system.

The determination of coordinates through the measurement done directly in the land implies the consideration of an appropriate measurement method with available instruments and, the localization of support points of the reference frame network to associate the surveying. The job is simpler if there are topographic charts that permit to take the coordinates from the control points. In this case, the precision of the georeferencing does not depend only on the adequate selection of points, but also on the accuracy of the chart. The procedure is considerably simplified when it is possible to take coordinates from another image already georeferenced, because there are more common features between two images than between an image and a chart. In consequence, control points can be localized not only in vertices of polygons, intersections of roads, intersections of roads with railways or intersections of roads with rivers – with bridges – but also, in vegetation areas that do not have a representation on the chart.

In order to select the control points, it has to be taken into account that the quality of the adjustment obtained by application of the functions of coordinates' transformation depends on the quality of the selected points, their correct localization and the distribution they have in the image. In this way, the quantity of required points varies in function of the size of the image and the topographic characteristics of the covering zone.

From a mathematical point of view, an adjustment of a first-degree equation requires a minimum of 3 points, a second-degree equation requires a minimum of 6 points and, a third-degree equation a minimum of 10 points. Nevertheless, different authors agree in recommending a selection of about 14 to 20 points for a full scene from the Landsat TM – or 25 points for a subscene –, advising that if it is possible, the points should locate uniformly in the image and especially over areas of different altitude.

As a result, the transformation of a coordinates' system is solved through two-dimensional functions (dimension x and dimension y), which in the simplest case implies the application of multiple linear regression.

$$x_i = a_0 + a_1 c_i + a_2 l_i$$
$$y_i = b_0 + b_1 c_i + b_2 l_i$$

Where a_0, a_1, a_2, b_0, b_1, b_2 are the regression coefficients, c_i and l_i the independent variables (column and row coordinates of the control points of the image without any corrections), whereas x_i and y_i are the dependent variables. The application of the linear functions permits rotation transformations, translation and change of scale and, for the coefficients' calculation, a method of minimum squares is used.

If a second-degree equation is applied instead of an adjustment first-degree equation, the function will be:

$$x_i = a_0 + a_1 c_i + a_2 l_i + a_3 c_i l_i + a_4 c_i^2 + a_5 l_i^2$$
$$y_i = b_0 + b_1 c_i + b_2 l_i + b_3 c_i l_i + b_4 c_i^2 + b_5 l_i^2$$

If an adjustment third-degree equation is applied, the function will be:

$$x_i = a_0 + a_1 c_i + a_2 l_i + a_3 c_i l_i + a_4 c_i^2 + a_5 l_i^2 + a_6 c_i l_i^2 + a_7 c_i^2 l_i + a_8 c_i^3 + a_9 l_i^3$$
$$y_i = b_0 + b_1 c_i + b_2 l_i + b_3 c_i l_i + b_4 c_i^2 + b_5 l_i^2 + b_6 c_i l_i^2 + b_7 c_i^2 l_i + b_8 c_i^3 + b_9 l_i^3$$

The position error (PE) for each *i* control point is given by:

$$EP_i = \sqrt{(\bar{c}_i - c_i)^2 + (\bar{l}_i - l_i)^2}$$

Where the correct coordinates are:

$$\bar{c}_i ; \bar{l}_i$$

The average of the position error of the control points provides a measurement of the general goodness of the adjustment:

$$\mathbf{EMP} = \frac{\boldsymbol{\Sigma}\ \mathbf{EP}_{\boldsymbol{i}}}{\boldsymbol{n}}$$

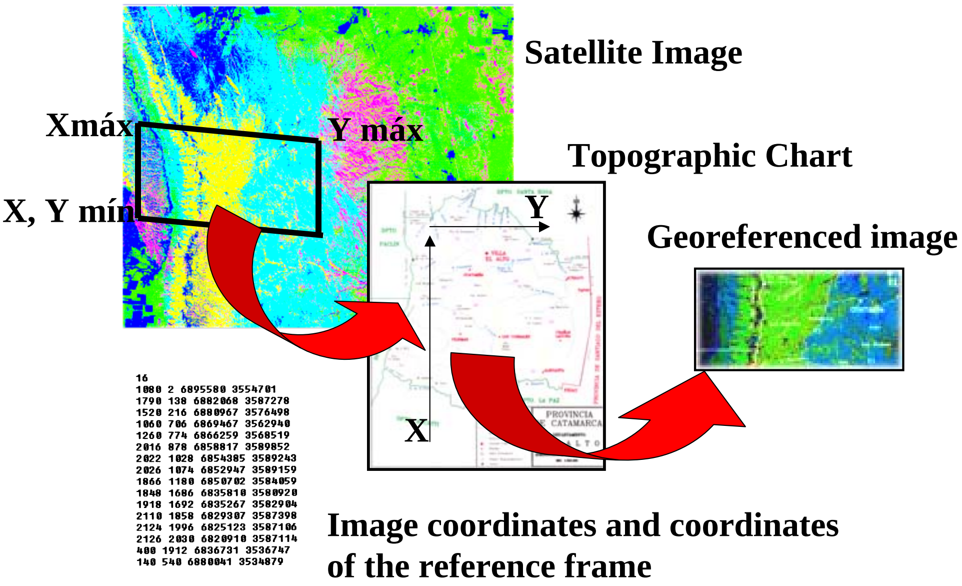
Where EMP is the medium position error and, *n* is the number of control points.
As the error is expressed in the units of the origin system, i.e. in pixels, if the result is one, this will mean in Landsat TM images, that the error is of 30 meters. In all these cases, it will be convenient to set the tolerance limits.

5. GEOREFERENCING PROCEDURE WITH IDRISI SOFTWARE

The procedure for satellite images georeferencing with Idrisi software implies, as a first step, the digitalisation of control points in the image and the record of those points in a vector file. Next, the image coordinates of the control points have to be taken in order to create a correspondence file – with the EDIT icon –, using the first line for the number of control points and, the subsequent lines for the pairs of coordinates correspondent to each point (image coordinates and coordinates of the reference frame).

The RESAMPLE icon of the Reformat menu permits to georeference the image and, in order to execute it, the image name, the output file name and the correspondence file name have to be entered. In addition, the reference system has to be selected. Moreover, there have to be entered the reference units, the distance units and the value to be used so as to complete the pixels. Otherwise, pixels can result without information if there is a rotation of the image (it adopts the zero value for black visual display). The information is completed with the maximum and minimum coordinates X,Y in the reference frame that is being used to georeference, with the number of columns [(MaxY-MinY)/Resolution] and, with the number of rows [(MaxX-MinX)/Resolution] of the output image.

Illustration 4: Georeferencing procedure with plane coordinates Gauss-Krüger of Topographic Chart



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16
1080 2 6895580 3554701
1790 138 6882068 3587278
1520 216 6880967 3576498
1060 706 6869467 3562940
1260 774 6866259 3568519
2016 878 6858817 3589852
2022 1028 6854385 3589243
2026 1074 6852947 3589159
1866 1180 6850702 3584059
1848 1686 6835810 3580920
1918 1692 6835267 3582904
2110 1858 6829307 3587398
2124 1996 6825123 3587106
2126 2030 6820910 3587114
400 1912 6836731 3536747
140 540 6880041 3534879
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Some of the problems that may appear in the application of the RESAMPLE icon, result from the need of establishing the coordinates of the borders of the image in the reference system. This means not only the individualization of control points but also, the individualization of points that limit the work area for the measurement with GPS and for the determination of coordinates in POSGAR.

As regards the reference system, Idrisi has approximately 400 parameters' files and it is still possible to create more files through the EDIT menu. Although it has the parameters' file of WGS 84, the Gauss Krüger system has to be edited taking into account which band the work area corresponds to. The eastern sector of the Province of Catamarca, for instance, corresponds to band 3, meridian -66º (West of Greenwich), with 0 origin of X abscissa in the South Pole and 3,500,000 for the central meridian.

Table 1: Information for georeferencing in the Campo Inchauspe 69 System

Band	Georeferencing Files for Idrisi Kilimanjaro
1	ref. system : Gauss-Kruger, Zone 1, Campo Inchauspe projection : Gauss-Kruger datum : Campo Inchauspe delta WGS84 : -148 136 90 ellipsoid : International 1924 major s-ax : 6378388 minor s-ax : 6356911.9 origin long : -72 origin lat : -90 origin X : 1500000 origin Y : 0 scale fac : 1.0 units : m parameters : 0
2	ref.system : Gauss-Kruger, Zone 2, Campo Inchauspe projection : Gauss-Kruger datum : Campo Inchauspe delta WGS84 : -148 136 90 ellipsoid : International 1924 major s-ax : 6378388 minor s-ax : 6356912 origin long : -69 origin lat : -90 origin X : 2500000 origin Y : 0 scale fac : 1.0 units : m parameters : 0
3	ref.system : Gauss-Kruger, Zone 3, Campo Inchauspe projection : Gauss-Kruger datum : Campo Inchauspe delta WGS84 : -148 136 90 ellipsoid : International 1924 major s-ax : 6378388 minor s-ax : 6356912 origin long : -66 origin lat : -90 origin X : 3500000 origin Y : 0 scale fac : 1.0 units : m parameters : 0
4	ref.system : Gauss-Kruger, Zone 4, Campo Inchauspe projection : Gauss-Kruger datum : Campo Inchauspe delta WGS84 : -148 136 90 ellipsoid : International 1924 major s-ax : 6378388 minor s-ax : 6356912 origin long : -63 origin lat : -90 origin X : 4500000 origin Y : 0 scale fac : 1.0 units : m parameters : 0
5	ref.system : Gauss-Kruger, Zone 5, Campo Inchauspe projection : Gauss-Kruger datum : Campo Inchauspe delta WGS84 : -148 136 90 ellipsoid : International 1924 major s-ax : 6378388 minor s-ax : 6356912 origin long : -60 origin lat : -90 origin X : 5500000 origin Y : 0 scale fac : 1.0 units : m parameters : 0
6	ref.system : Gauss-Kruger, Zone 6, Campo Inchauspe projection : Gauss-Kruger datum : Campo Inchauspe delta WGS84 : -148 136 90 ellipsoid : International 1924 major s-ax : 6378388 minor s-ax : 6356912 origin long : -57 origin lat : -90 origin X : 6500000 origin Y : 0 scale fac : 1.0 units : m parameters : 0
7	ref.system : Gauss-Kruger, Zone 7, Campo Inchauspe projection : Gauss-Kruger datum : Campo Inchauspe delta WGS84 : -148 136 90 ellipsoid : International 1924 major s-ax : 6378388 minor s-ax : 6356912 origin long : -54 origin lat : -90 origin X : 7500000 origin Y : 0 scale fac : 1.0 units : m parameters : 0

In the Idrisi Kilimanjaro's version, the information that has to be included in order to georeference in Gauss-Krüger coordinates for the Campo Inchauspe 69 system is contained in Table 1.

Different authors have pointed out the need of analyzing carefully what is the most appropriate moment to make the georeferencing, since traditionally, it was considered to be a previous step to any procedure with images. Currently, taking into account the classification, it is convenient to georeference a classified image to elude the difficulty of losing the original digital levels. This loss inevitably occurs as a result of the transformation.

The transformations of the coordinates' system of the image permit to calculate the exact position of each pixel; as a consequence, a corrected matrix is obtained. In this matrix the digital levels have to be located. It is common that the pixel of the new image will be located among many pixels of the original image. For this purpose, there are three methods:

- Nearest neighbour: it takes the digital level of the pixel of the original image which is near the calculated coordinates. It has the advantage that it is a fast method and that it ensures that the pixel value really exists. The disadvantage is the introduction of nonlinear features, like breaks in straight lines. It is the only method that can be applied to classified images, because averages of qualitative digital values do not make sense.
- Bilinear interpolation: it interpolates the value of the four pixels that are nearest the calculated point, providing a smoother result.
- Cubic convolution: it consists of adjustments with third-degree polynoms, taking into account the nearest 16 points.

6. FINAL REMARKS

Adjustments do not guarantee – in the strict sense – that the image will adapt totally to the new reference system: the correction of the transformation is only guaranteed in the support points, not in every image point; consequently, it is better to use a more numerous set of support points in order to make the transformation equations. Redundancy of data permits the goodness of the adjustment to have meaningful statistics and, gives an idea of to what extent, transformation equations could relate support points in both systems. Georeferencing quality can only be estimated from a set of control points different from the support points.

Finally, in countries like Argentina, where different reference systems coexist, there has to be taken special care when using different data sources (coordinates taken from charts and coordinates taken from the ground) because they are not always compatible.

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BIOGRAPHICAL NOTES

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She holds a PhD. degree from the National University of Catamarca, Argentina (2000) with the thesis *"Satellite images application in massive rural valuations"*. She is a Professor of "Physic Geography" and "Remote Sensing", full-time from 1996, at the School of Technology and Applied Sciences of the National University of Catamarca. She is the Academic Director of the Surveying Doctorate Career, from 2002, at the National University of Catamarca (Argentina). She has published extensively in the areas of remote sensing applications and curriculum development in surveying. She is a FIG Commission 2 Argentine Delegate from 2004.

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