# Self-calibration methods for using historical aerial photographs with photogrammetric purposes

**AGUILAR TORRES, Manuel Ángel**
**AGUILAR TORRES, Fernando José**
**MARQUES NEGREIRO, Joao Garrott**

*Universidad de Almería*
*Lusófona University, Lisbon*

**ABSTRACT**

The historical aerial photographs are taking a fundamental importance for spatial analysis of the territory. Appropriate comparison of photogrammetric surveys of a particular zone carried out in different years allows the identification of geometric changes occurring during the time interval in question. This technique has many fields of application such as evolution of coastlines or landslide monitoring. The main mathematical principles used in photogrammetry are based on the collinearity equations, which allows three-dimensional coordinates to be extracted from stereo photographs. Camera parameters and ground control points (GCPs) are required for obtaining a photogrammetric solution. When the parameters that define the camera calibration are not known (this is the most usual thing when we work with historical flight), then they should be evaluated by a process called self-calibrating bundle adjustment. Leica Photogrammetry Suite (LPS) offers several models for self-calibration such as models of Bauer, Jacobsen, Ebner, and Brown.

In this research, a stereo pair from a photogrammetric flight at a scale 1:5000 was used. Full details of camera calibration data used were supplied. Within the work area, 87 randomly distributed ground points were selected. These points were located on well- defined natural and man-made features in both digital images. Differential global positioning system observations were used to measure ground points. The aim is to study the influence of different self-calibration methods on the accuracy of three-dimensional coordinates and Digital Elevation Models (DEMs) generation. We test six photogrammetric projects: (1) without self-calibration, by setting the principal point coordinates to zero, and fixing the value of focal length, which is usually known as a marginal data in the photograph, (2) based on the previous project but adding Bauer's model as self-calibration, (3) using Jacobsen's model, (4) Ebner's, (5) Brown's, and the best possible project, (6) using the full information about the camera included in the camera calibration certificate. All these projects were computing using 24 and 12 GCPs respectively. Ebner's orthogonal model, with twelve additional parameters and with 24 GCPs, was the best option for self-calibration, presenting accuracies very close to the projects that used camera calibration data, being their DEMs almost identical.

**Keywords:** Self-calibration, triangulation, accuracy, digital elevation model, historical aerial photographs.

## 1. Introduction

The benefits of using aerial photography are relatively well understood, though the use of historical aerial photography is less developed. Nowadays, the aerial photography, and concretely the temporary series of the same ones, is the information more frequently used in the studies of change analysis in the territory [1], [2], [3], [4].

In Spain have been carried out numerous studies that use temporary series of historical photographs to study the shoreline change (accretion/erosion) in the last 50 years on coasts of Catalunya [5], [6], in the river mouth of the river Vélez, Malaga [7], in the beaches of Fuerteventura [8], on the coast between Sanlúcar de Barrameda and Rota, Cadiz [9], or on the coast of Almería between the beaches of the Almería and Retamar [10]. Other works fulfilled in Spain use historical series of aerial photographs for the study of landslides [11] or for the land use analysis [12].

The majority of these works use, as photogrammetric flight more ancient, the acquaintance as “American Flight” of 1956-57. It was the first photogrammetric project to cover the most part of Spain, and it was done by U.S. Government. Thus, it is a valuable information source for photo interpretation and land use evolution. But, large problems with the present metric use of this flight, in the same way that others historical flights, are existing. The proper conservation of the prints is not guaranteed and there is and important lack of data respect to the cameras employed, not existing calibration certificate of these. Moreover, usually there are not fiducial marks in these photographs, and they are not suitable for inner orientation in the modern Digital Photogrammetric Workstation [11]. Another general problem when a historical flight is used for metric purposes, is the difficulty to find control points, both in quantity and sufficient quality, because the possible good points that we can see in the image, they already are not on the ground [11], [13], [14].

The main mathematical principles used in photogrammetry are based on the collinearity condition, which allows three-dimensional coordinates to be extracted from stereo photographs. Camera parameters and ground control points (GCPs) are required for obtaining a photogrammetric solution. When the parameters that define the camera calibration are not known (this is the most usual thing when we work with historical flight), then they should be evaluated by a process called self-calibrating bundle adjustment, e.g., [15], [16]. Self-calibration is a well known method that it has been successfully and routinely applied in close range photogrammetry applications with non metric cameras, but in recent years, self-calibration is also being used in aerial photogrammetry. In fact, most present Digital Photogrammetric Workstations are incorporating triangulation software which offers this advanced option.

The aim of this work is to study the influence of different self-calibration methods and the number of GCPs used, on the accuracy of three-dimensional coordinates attained for 63 independence check points (ICPs) from a stereo pairs composite by two overlapped aerial photographs. These results will be compared with the photogrammetric project using the full information about the camera used to take the photographs, included in the camera calibration certificate. Also DEMs generated by each project were compared. The final results could be used as reference for self-calibration of historical flights.

## 2. Methodology

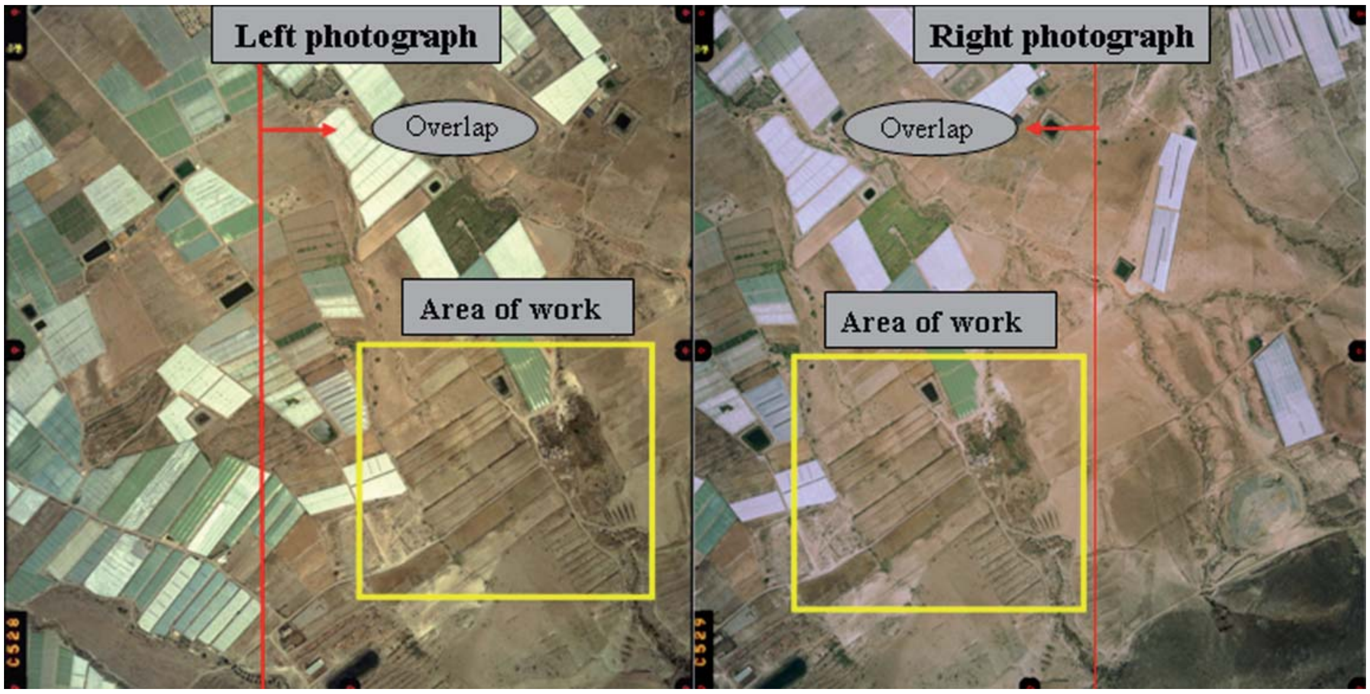
### 2.1 Photogrammetric flight

The colour photographs used in this study belong to a photogrammetric flight at an approximate scale of 1:5000 with 60% and 25% forward and side overlap, respectively. It was commissioned by the State-owned Company for the Agrarian and Fishing Development of Andalusia (D.a.p.) and carried out on 15th May 2001, covering an area of around 160 km$^2$ in Almería, Spain. The camera used was an RMK TOP 15 with a wide-angle lens (focal length of 153.33 mm) and the film chosen was AGFA AVIPHOT H100. Full details of camera calibration data were supplied. For this study a stereo pair of this flight comprising photographs 528 (left) and 529 (right) was selected (Figure 1).

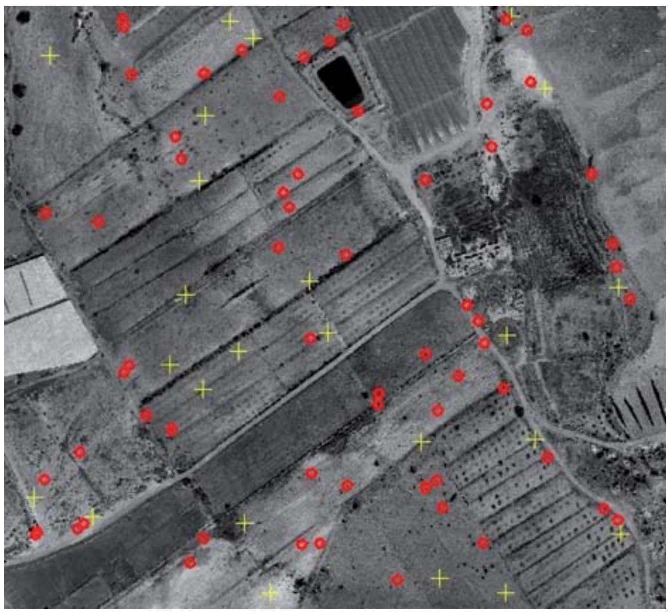
The photographs were scanned using a Vexcel UltraScan 5000 photogrammetric scanner at a geometric resolution of 20 μm per pixel (≈1270 dpi) and a colour depth of 24 bits (true colour). The digital images were stored in TIFF format.

### 2.2. Ground Control and Check Points

The work area was reduced to approximately 500 m per 450 m (Figure 1) which occupied 25% of the overlapping surface of the stereo pair. Within the work area, 87 randomly distributed ground points were selected. These points were located on well-defined natural and man-made features in both digital images (such as corners of irrigation




| **Figure 1.** Left and right photographs and work area



| **Figure 2.** Distribution of check (red circles) and control (yellow cross) points in the work area

outlet boxes, greenhouses, irrigation pipes, bushes and rocks). Differential global positioning system (DGPS) observations were used to measure these ground points [17]. This method offered an accuracy of around 0.15 m.

Of a total of 87 ground points collected, 63 were retained as ICPs in order to compare the photogrammetrically extracted data coordinates with the corresponding ground survey values. The remaining 24 points were used as GCPs, in the first case studied and, only 12 of them, in the second case. Around 12-16 GCPs were used by Walstra [13] in a similar research with historical photographs. Always, ICPs and GCPs were well distributed inside of work area (Figure 2).

### 2.3 Photogrammetric projects

In this work, 12 photogrammetric projects (six with 24 GCPs and six with 12 GCPs) were carried out using the stereo pair described previously and Leica Photogrammetry Suite (LPS), from Leica Geosystems Geospatial Imaging, LLC. In all of them, GCPs and ICPs were pointed in the same way on the image space.

One of them was obtained using full details of camera calibration data (focal length, principal point, fiducial marks, and radial and decentering distortions). This project was called “Ideal”.

For the second project, the corners coordinates for each photograph were established using precise manual measurements made on the positives, and they were used as fiducial marks. The principal point coordinates are fixed at zero, i,e., no offset existed between the principal point and the fiducial centre. Focal length was included because it usually appears as marginal data in aerial photographs. This project was named “Only Focal Length”.

Based on Only Focal Length project, the other four photogrammetric projects were attained using different Additional Parameters (APs) models included as advanced options in aerial triangulation module of LPS. The APs are the terms of a polynomial expression incorporated in the collinearity equations, and they allow for the modelling of various systematic errors, such as lens distortion. In LPS, four APs models can be used in the triangulation process [18], including:

- **Bauer's Simple Model.** This model has three APs, two parameters mainly determine the extent of affine deformation and one parameter estimates symmetric lens distortion. We will refer to this project as "Bauer".

- **Jacobsen's Simple Model.** This model has four APs, which compensate for the first and second order distortions associated with affine deformation and lens distortion. We will refer to this project as "Jacobsen".

- **Ebner's Orthogonal Model.** This model has twelve APs, which compensate for various types of systematic error including lens distortion, scanner error, affine deformation, and film deformation. Since a greater number of parameters are being estimated, an increased number of GCPs are required. We will refer to this project as "Ebner".

- **Brown's Physical Model.** This model has fourteen APs, which compensate for most of the linear and nonlinear forms of film and lens distortion. We will refer to this project as "Brown".

### 2.4 Photogrammetric projects comparison

To evaluate the different projects generated in this work, we have used two ways:

(i) To compute the Root Mean Square error (RMS) at the 63 ICPs for each spatial direction. Thus, a global measure of the error was attained. RMS for the X, Y, Z were computed by equations 1, 2 and 3, where n is the number of ICPs; (XiDGPS, YiDGPS, ZiDGPS) are the ICPs coordinates measured with DGPS and (XiPP, YiPP, ZiPP) are the ones obtained with the photogrammetric project.

$$RMS_x = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_{i\,DGPS} - X_{i\,PP})^2} \quad (1)$$

$$RMS_y = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_{i\,DGPS} - Y_{i\,PP})^2} \quad (2)$$

$$RMS_z = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_{i\,DGPS} - Y_{i\,PP})^2} \quad (3)$$

(ii) To verify that the photogrammetric projects computed are free of systematic errors, DEMs generated from them were compared using RapidForm software (INUS Technology). DEMs were automatically extracted by LPS with a strategy showed in Table 1 and with 1 m grid spacing. These DEMs were interpolated using Multicuadric Radial Basis Function with four sectors to search and with a maximum of 64 data, obtaining grid DEMs with 2 m pixel spacing. Multicuadric Radial Basis Function was proposed by [19] as the most reliable interpolation method for filling the sampling gaps produced in DEMs.

| Strategy Parameter Setting | Values |
|---|---|
| Search Size | 21 x 3 |
| Allow Adaptative Change | No |
| Correlation Size | 7 x 7 |
| Coefficients Limits | 0.800 |
| Topographyc Type | Rolling Hills |
| MDE Filtering | Low |

| **Table 1.** Strategy Parameter Setting in LPS to extract DEMs

## 3. Resuls and discussion

### 3.1 Photogrammetric flight

The first results are showed in Table 2, containing RMS values obtained at 63 ICPs for the six photogrammetric projects computed with 24 GCPs. In this case, the projects named Ideal and Ebner presented the best accuracies for X, Y and Z directions, followed very closely for Brown's model.

Worse results in Table 2 were attained using Jacobsen and Bauer models, especially in Z axis, where relative accuracies difference of around 25% were attained respect the RMS from Ideal project. The project without self-calibration model (Only Focal Length) showed the worst accuracies, reaching at axis Z up to 83 per cent. Really, 24 GCPs are many points, which not always are possible to obtain in field, especially when one works with historical photos.

| Models | RMS Check Points (m) | | |
|---|---|---|---|
| | X | Y | Z |
| Ideal | 0.066 | 0.097 | 0.097 |
| Only Focal Lenght | 0.116 | 0.121 | 0.178 |
| | (75.8%) | (24.7%) | (83.5%) |
| Bauer | 0.070 | 0.099 | 0.122 |
| | (6.1%) | (2.1%) | (25.8%) |
| Jacobsen | 0.071 | 0.098 | 0.120 |
| | (7.6%) | (1.0%) | (23.7%) |
| Ebner | 0.065 | 0.098 | 0.098 |
| | (-1.5%) | (1.0%) | (1.0%) |
| Brown | 0.065 | 0.099 | 0.104 |
| | (-1.5%) | (2.1%) | (7.2%) |

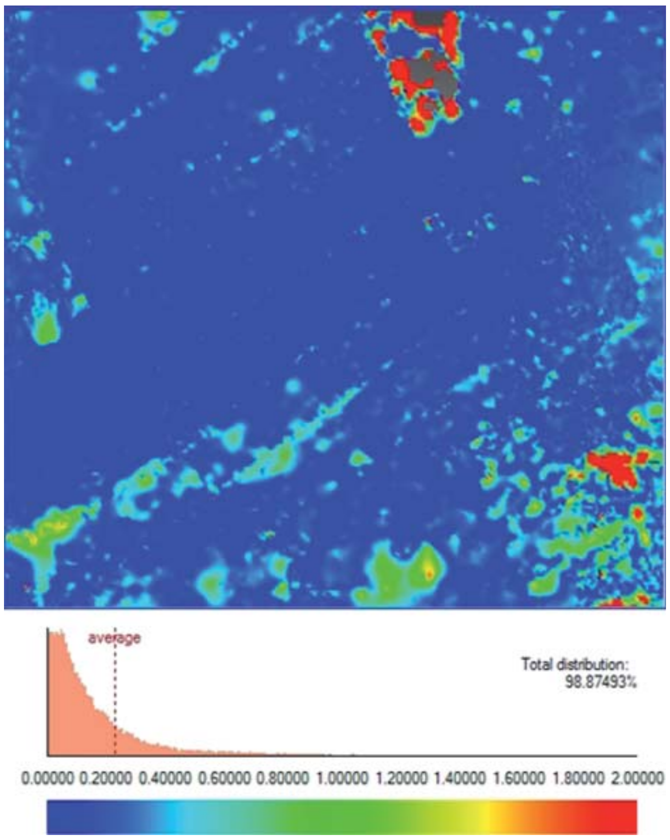
| **Table 2.** Root Mean Square errors obtained at 63 Check POints for the six photogrammetric projects using 24 GCPs. Relative differences in percentage respect Ideal project in brackets

| Models | RMS Check Points (m) | | |
|---|---|---|---|
| | X | Y | Z |
| Ideal | 0.071 | 0.099 | 0.094 |
| Only Focal Lenght | 0.132 | 0.118 | 0.176 |
| | (85.9%) | (19.2%) | (87.2%) |
| Bauer | 0.072 | 0.105 | 0.141 |
| | (1.4%) | (6.1%) | (50.0%) |
| Jacobsen | 0.075 | 0.108 | 0.143 |
| | (5.6%) | (9.1%) | (52.1%) |
| Ebner | 0.066 | 0.106 | 0.113 |
| | (-7.0%) | (7.1%) | (20.2%) |
| Brown | 0.067 | 0.109 | 0.131 |
| | (-5.6%) | (10.1%) | (39.4%) |

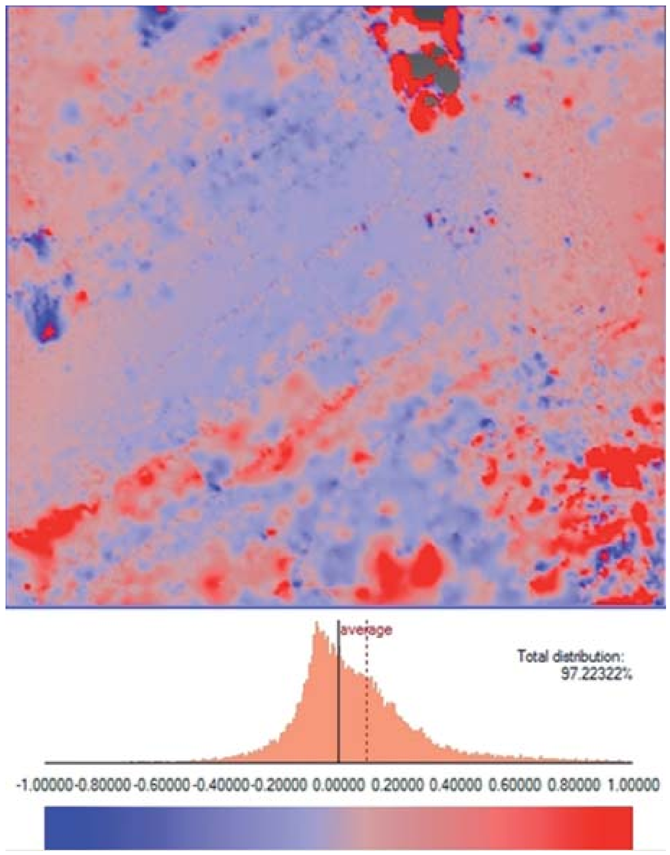
| **Table 3.** Root Mean Square errors obtained at 63 Check Points for the six photogrammetric projects using 12 GCPs. Relative differences in percentage respect Ideal project in brackets

| General Mass Points Quality | Ideal Project | | Ebner's model | |
|---|---|---|---|---|
| | 24 GCPs | 12 GCPs | 24 GCPs | 12 GCPs |
| Excellent (%) | 61.04 | 60.86 | 55.17 | 54.99 |
| Good (%) | 25.75 | 25.88 | 28.57 | 28.74 |
| Fair (%) | 0 | 0 | 0 | 0 |
| Insolated (%) | 0 | 0 | 0 | 0 |
| Suspicius (%) | 13.21 | 13.26 | 16.26 | 16.27 |

| **Table 4.** Accuracy information for DEM extraction process




| **Figure 3.** Comparison, in absolute deviation values, between grid DEMs from Ideal and Ebner projects with 12 GCPs




| **Figure 4.** Comparison, in signed colour mode, between grid DEMs from Ideal and Ebner projects with 12 GCPs

When only 12 GCPs were uses for triangulation process (Table 3), accuracies obtained are worse than the attained with 24 GCPs. Again, the best self-calibration model was Ebner, though presenting higher relative difference at Z axis (around 20%). Brown, Bauer, Jacobsen and Only Focal Length, in this order, were the following projects. Ideal project was the only one that did not accuse the decrease of GCPs.

It seems to be clear that Ebner's model is the more effective model to reduce the systematic errors, improving even the Brown's model, in spite of having two coefficients less. Our results coincide with the obtained before by Cardenal *et al.*, [11], where Ebner's model was signed, working with a historical flight, as the best APs model inside advanced options that LPS offers.

But although Ebner's model has shown to be the best self-calibration model tested in this work, it is very important to study the behaviour of DEMs generated by this photogrammetric project regard to the extracted ones from the Ideal project. With DEMs comparison we want to verify the kindness of the Ebner's model.

The comparison between grid DEMs from Ideal and Ebner projects with 12 GCPs are showed in absolute deviation values (Figure 3), presenting an average distance of 0.23 m and a standard deviation of 0.56 m. The highest errors (around 2 m) were appearing on the plastic covering the greenhouses, where the reflective properties of the material were provoking stereo-matching working bad.

In Figure 4 real discrepancies between grid DEMs from Ideal and Ebner projects with 12 GCPs are showed in signed colour mode. There are not important systematic mistakes, being the mean value of 0.09 m. Note that DEMs are not edited.

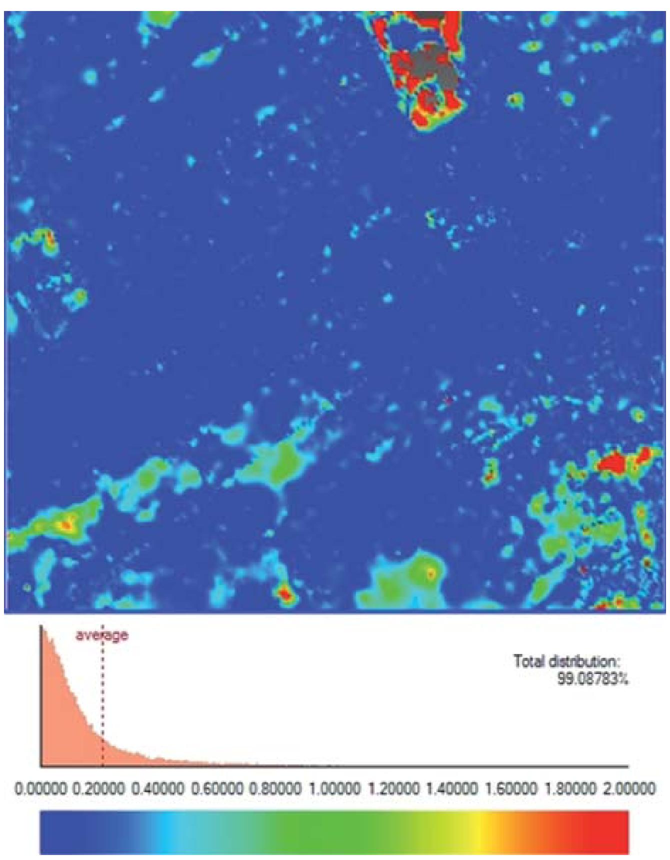
The comparison between grid DEMs from Ideal and Ebner projects with 24 GCPs are showed in Figure 5 and Figure 6. In these figures we can see something similar to the previously showed in Figures 3 and 4, though now, DEMs extracted using 24 GCPs are even more seemed, presenting an average distance of 0.21 m (absolute values in Figure 5) and a mean value of only 0.07 m (signed colour mode in Figure 6).

Table 4 shows the accuracy information in percentage for DEMs extraction process carried out by LPS software. The quality statistics about mass points for Ideal projects were better than for Ebner projects, both for 12 and for 24 GCPs.

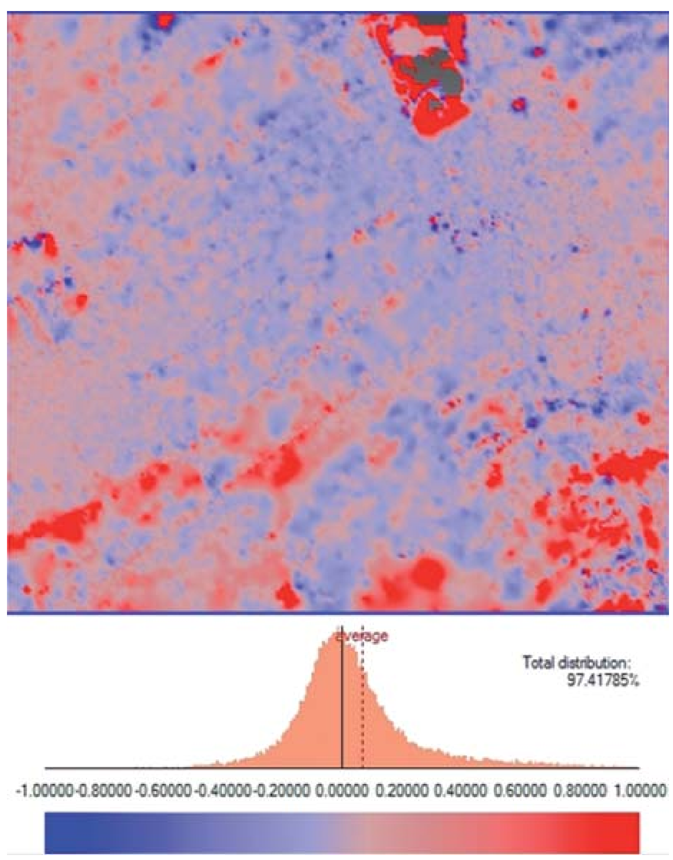
Other strategy for computing self-calibration could be performed by using an external program as GAP (General Adjustment Program) developed by Clarke and Chandler [20], or PhotoModeler Pro 5 (Eos System Inc., Vancouver, Canada). After successful recovery of the interior orientation (focal length, principal point offsets and parameters for radial distortion) these parameters were transferred back into LPS. This strategy has already been used with historical flights [13], and could be tested in further works by our group.

## 4. Conclusions

The results obtained in this work present to Ebner's orthogonal model as the most accurate self-calibration with additional parameters model included in LPS software. This model has twelve parameters but it improves the accuracies attained by more complex models (e.g., Brown's model). To be




| **Figure 5.** Comparison, in absolute deviation values, between grid DEMs from Ideal and Ebner projects with 24 GCPs




| **Figure 6.** Comparison, in signed colour mode, between grid DEMs from Ideal and Ebner projects with 24 GCPs

more precise, when Ebner's model was used with 24 GCPs, RMS attained at 63 ICPs was almost equal to the generated ones by the photogrammetric project using full information of the camera calibration certificate. Anyway, obtaining good ground points can be extremely difficult in historical aerial flight, especially if changes in landscape are large. Thus, with only 12 GCPs, Ebner's model worked quite well at $X$ and $Y$ axes, though in $Z$ axis, a relative difference with regard to Ideal project was placed close to 20%.

Regarding the comparative between DEMs extracted from Ideal and Ebner projects, both in absolute values and in signed colour mode, showed that did not exist systematic errors.

## 5. Acknowledgments

The authors greatly appreciate the cooperation of State-owned Company of the Agrarian and Fishing Development of Andalusia, Spain. Thanks are due to J. Delgado and F. Javier Cardenal from Jaén University. This work has been supported by the Andalusia Government by means of the research project P08-RNM-03575 (2009-2012).

## References

[1] IVERSON, L.R., GRAHAM, R.L., COOK, E.A. (1989) "Applications of satellite remote sensing to forested ecosystems". *Landscape Ecology*, 3(2), 131-143.

[2] DUNN, C.P., SHARPE, D.M., GUNTENSPERGEN, G.R., STEARNS, F., YANG, Z. (1990) "Methods for analyzing temporal changes in landscape pattern". In Turner, M.G. y Gardner, R.H. (Eds.) *Quantitative methods in Landscape Ecology. The analysis and interpretation of landscape heterogeneity*. Springer-Verlag. New York. 536 pp.

[3] GREEN, K., KEMPKA, D., LACKEY, L. (1994) "Using remote sensing to detect and monitor land-cover and land-use change". *Photogrammetric Engineering and Remote Sensing*, 60(3), 331-337.

[4] ZHENG, D., WALLIN, D.O., HAO, Z. (1997) "Rates and patterns of landscape change between 1972 and 1988". in the Changbai Mountain area of China and North Korea. *Landscape Ecology*, 12, 241-254.

[5] CROUS, A., VARGA, D., PINTÓ, J. (2004) "Cálculos y técnicas SIG para la gestión del espacio costero. Determinación de zonas vulnerables en el hemidelta norte del Ebro a partir del cálculo del retroceso de la playa de la Marquesa". In Actas del *XI Congreso de Métodos Cuantitativos, SIG y Teledetección, Territorio y medio ambiente: métodos cuantitativos y técnicas de información geográfica*, Murcia, España.

[6] CROUS, A. PINTÓ, J. (2006) "Evolución de la playa de Sa Riera (Cap de Begur, Costa Brava) en los últimos 50 años". *Investigaciones geográficas*, 39, 119-130.

[7] SENCIALES, J.M., MALVÁREZ, G. (2003) "La desembocadura del río Vélez (Provincia de Málaga, España). Evolución reciente de un delta de comportamiento mediterráneo". *Rev. C. & G.*, 17(1-2), 47-61.

[8] ALONSO, I, CABRERA, L.L., JIMÉNEZ, J.A, VALDEMORO, H.I., SÁNCHEZ, I. (2007) "Aplicación de la fotogrametría a estudios de erosión costera". In Actas del *XII Congreso de la Asociación Española de Teledetección*, Mar del Plata, Argentina.

[9] DOMÍNGUEZ, L., GRACIA, F.J., ANFUSO, G. (2004) "Tasas de avance/retroceso de la línea de costa mediante morfometría fotogramétrica en el sector Sanlúcar de Barrameda-Rota (provincia de Cádiz)". *Rev. Soc. Geol.* España, 17 (1-2): 71-86.

[10] MANZANO, G., MUÑOZ, A., MANZANO, F. (2004) "Estudio de la evolución de la línea de costa entre Almería y Retamar mediante la integración de diferentefuentes de información en un SIG". In XVI Congreso Internacional de Ingeniería Gráfica, *Actas del Congreso*, Zaragoza-Huesca, España.

[11] CARDENAL, J., DELGADO, J., MATA, E., GONZÁLEZ, A., OLAGUE, I. (2006) "Use of historical flight for landslide monitoring". In *Proceedings of Accuracy 2006, 7th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences*, Lisboa, Portugal, M. Caetano and M. Painho (Eds.), pp. 129-138.

[12] MARTÍNEZ, J.E., MARTÍN, J., SEVA, E. (2000) "Paisajes amenazados de la cuenca mediterránea. Aplicacion del SIG en el análisis de la dinámica de usos del territorio (1956-1998) en la Vall de Gallinera (Alicante-España)". *Mediterránea. Serie de Estudios Biológicos*, Época II, 17, 51-60.

[13] WALSTRA, J. (2006) *Historical Aerial Photographs and Digital Photogrammetry for Landslide Assessment*. PhD Thesis, Loughborough University, Loughborough, UK.

[14] ZANUTTA, A., BALDI, P., BITELLI, G., CARDINALI, M., CARRARA, A. (2006) "Qualitative and quantitative photogrammetric techniques for multi-temporal landslide analysis". *Annals of Geophysics*, 49(4/5), 1067-1080.

[15] GRANSHAW, S.I. (1980) "Bundle Adjustment Methods in Engineering Photogrammetry". *The Photogrammetric Record*, 10(56), 181-207.

[16] CHANDLER, J.H., COOPER, M.A.R. (1989) "The Extraction of Positional Data from Historical Photographs and Their Application to Geomorphology". *The Photogrammetric Record*, 13(73), 69-78.

[17] AGUILAR, M.A., AGUILAR, F.J., AGÜERA, F., (2005) "Mapping small areas using a low- cost close range photogrammetric software package with aerial photography". *The Photogrammetric Record*, 20(112), 335-350.
[18] LEICA GEOSYSTEMS (2003) *Leica Photogrammetry Suite Orthobase & Orthobase Pro User's Guide*. Leica Geosystems GIS & Mapping, LLC, Atlanta, Georgia: 516 pp.
[19] AGUILAR, F.J., AGÜERA, F., AGUILAR, M. A., CARVAJAL, F. (2005) "Effects of terrain morphology, sampling density, and interpolation methods on grid DEM accuracy", *Photogrammetric Engineering and Remote Sensing*, 71 (7), 805-816
[20] CLARKE, J.S., CHANDLER, J.H. (1992) "The Archival Photogrammetric Technique: Further Application and Development". *Photogrammetric Record* 14 (80): pp. 241-247.