GIS Applications in Easter Island: Geodetic adjustments and survey maps accuracy[1]

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ABSTRACT. This paper discusses the variables and methodology involved in the geodetic transformations required for the adjustment of the Easter Island Archaeological Survey's cartography –until recently supposed to be in Datum Easter Island 1967- into the current world geodetic system WGS84, base of the NAVSTAR GPS system, and explores the limitations for archaeological fieldwork of the absolute method used by the "satellite navigators" in relation with the cartographic scales considered.

Recent research on Easter Island involving local survey done with GPS technology, led some scholars to speculate that the maps of the island-wide archaeological survey started in 1968 are inaccurate or simply wrong when data are compared with GPS generated georeferenced locations of geographical features and archaeological features and sites.

This paper discusses the true nature of the problem, warns on the indiscriminate use and current limitations of GPS surveying on the island without the control and corrections we analyze and -by validating the accuracy of the published survey cartography- proposes the procedures required to make such adjustments and the correct lecture and use of the archaeological survey's site locations maps.

The cartographic base on which the Easter Island Archaeological Survey [3] is sustained comes from an analogical aerophotogrametric restitution done at 1:10,000 scale, carried out by the "Servicio Aerofotogramétrico de la Fuerza Aérea de Chile' (SAF) in July 1965, based on aerial photographs taken in January 1964 at an average scale of 1:17,500 (effective at sea level). Its georeference corresponds to an astronomical datum, supposedly established over the '1924 International Ellipsoid'. Such restitution, with a 5 meter contour interval, constitutes a detailed registry of the morphological features and historical planimetric elements we can find on the island surface and, together with derived maps on scales 1:25,000 and 1: 30,000 it was officially used until 2005.

In order to work with sheets on a suitable scale for cartographic registry in areas with high density of archaeological sites, the original charts 1:10,000 were enlarged by William Mulloy to a scale of 1:5,000, and the island was arbitrarily divided into 35 quadrangles covering 2.5 km east-west by 3 km north-south. Since 1977 the authors refined this cartography and, as the

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[3] i.e. McCoy, 1976; Cristino and Vargas, 1980; Cristino, Vargas and Izaurieta, 1981; Cristino, Vargas, Izaurieta and Budd, 1988; Vargas, 1998; Vargas, Cristino and Izaurieta, 2006.

survey systematically covered the island, generated field-adjusted topographic maps and georeferenced the 35 quadrangles originally designed by Mulloy (Figure 1).

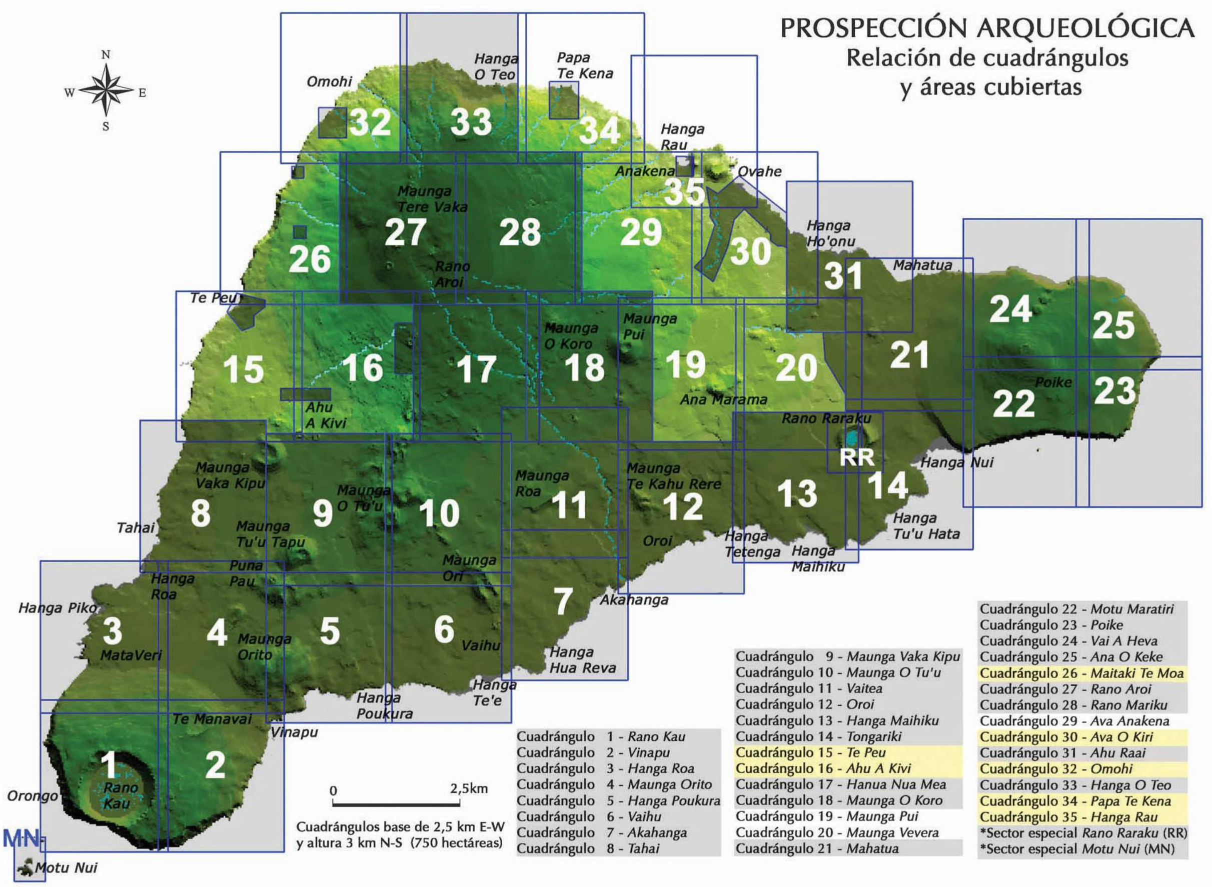

Figure 1: Easter Island Archaeological Survey, Key to Quadrangles. From Vargas, Cristino, Izaurieta, 2006.

In its early stages, the archaeological survey used plane table surveying methods for the topographic registry of sites directly over the quadrangles sheets, but due to the low precision of the graphic determination of directions plus the negative effects of the island weather conditions in the exposed paper dimensional stability, the plane table usage was replaced in 1978 by a faster and more accurate tachymetric method and frequent control measures were made to the planimetric and orographic elements depicted in the maps. Local ‘Connecting Traverses’, used as the basis for the topographical surveys, always started and ended in points with known cartographic position.

Control measures were made in the field to ensure that the archaeological sites would show in their true positions with respect to landscape features and elements depicted (natural and manmade features) in each of the quadrangle maps, as well as with true orientations and dimensions in the case of large structures (*ahu*), long stone alignments and intra-site features. In this way, any mapped site would be easily identified in the field by reading correctly the landscape features represented in its vicinity and its spatial relation to other sites. Several site relocation activities carried out in this traditional way in different parts of the island, in different times and for different purposes, have shown that, for trained people, this method always works. The only key is to know how to read a topographic map and use it for orientation in the field.

The development of new technologies, especially as from the 1980s, totally changed not only the way maps are produced, but also how they are used and handled. Digital maps, in addition to computer aided design (CAD), geographic information system (GIS) developments, remote sensing/satellite imagery, global positioning systems (GPS) and electronic developments for field measurements, dramatically improved accuracy and efficiency, extending mapping beyond its traditional boundaries.

In 1982 the SAF carried out a second aerophotogrametric flight, with an average scale of 1:25,000 covering the whole island, larger scales 1:5,000 for Hanga Roa, the west coast and *Rano Raraku* and 1:2,000 for the landing field at the airport. The 1:25,000 scale aerial photographs were the basis for a new map 1:5,000 covering *Hanga Roa* and the modern agricultural areas surrounding the town, made at the Easter Island Studies Centre[4]. The field network of control points for the aerophotogrametric restitution was based on three permanent landmarks still in the area, all of them of known geodetic position in exactly the same reference system used by the 1965 restitution. Regardless of minor differences shown in the shape of some contour lines (mainly due to the action of different operators in different restitution processes at different times), the resulting cartography matched accurately with the SAF charts.

Our first apprehensions about the georeference system of Easter Island cartography arose in 1992 while testing a Sony GPS receiver, to be used in the initial mapping of areas related to the research project and restoration of *Ahu Tongariki*. The positioning results, as given by the receiver for Easter Island datum, differed strongly from those obtained by direct cartographic reading -vector errors were larger than 150 meters. However, aware of the limitations of an elementary GPS passive receiver, clock synchronization errors, pseudo ranging method restrictions and the random error (Selective Availability) introduced intentionally by the USA Defence Department at that time, the fieldwork continued in the usual form and no further inquiries were made about these problems at that time.

In 1993, the authors incorporated GIS technology to the Easter Island Archaeological Survey Program, with the sponsorship of ESRI Chile (at that time INCOM), through the ESRI software Arc/INFO PC and ArcView (Vargas et al., 1996; 1998:147-152). Quadrangles were digitized, creating significant thematic layers (coverage), and all the information was georeferenced according to the geodetic information shown in the original charts.

In 1998, in the course of a field season of the project “GIS Mapping techniques on Easter Island” carried out by the authors and Anthony Huntley from Saddleback College, California, georeferenced data for digital mapping of the prehistoric settlement in the environs of *Ahu Tongariki* and *Ahu Tepeu* were collected. Sponsored by ESRI, Trimble Navigation Ltd. and

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[4] Izaurieta 1982, this was possible thanks to the financial support of Dr. Joan Seaver, Associate researcher, UCLA.

Topcon Corporation, we used DGPS post process methods with Trimble Pathfinder Receivers and took direct measures in the field with a Topcon Electronic Total Station.

As NAVSTAR GPS depicts Earth locations on the ‘World Geodetic System 1984’ (WGS 84), which differs in size and position from any other geodetic datum defined locally for mapping, a coordinates transformation process had to be done for each position in order to fit with the local cartography (figure 2).

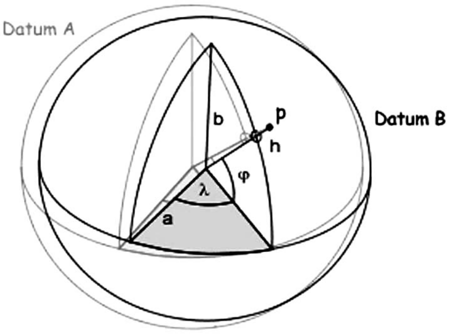

Illustration of a datum shift and rotation of one datum system with respect to another. The centres of the ellipsoids do not coincide and the axes are rotated.

Figure 2: Same point (p), difent Datum, diferent coordinates.

This was solved internally by the GPS software, selecting UTM coordinates on the predefined datum ‘Easter Island 1967’ as the desired output format. However, this resulted in great displacement, of about 160 meters, for all points at *Ahu Tongariki* and *Tepeu*, evidencing an error in the identification of the target datum, and consequently in the parameters used for the transformation process (see figure 3).

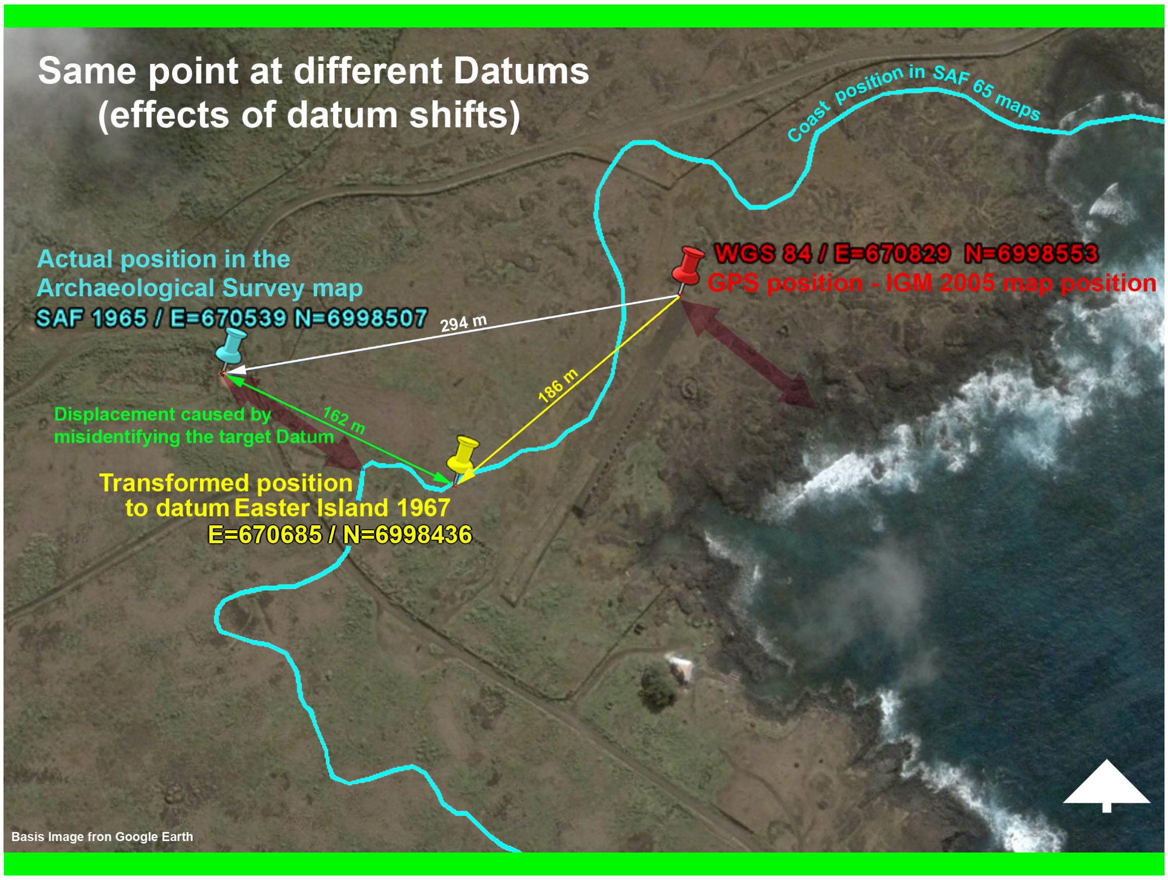

Figure 3: Displacements determined at Ahu Tongariki between SAF 65 charts, Datum WGS 84 georeferenced image and transformed position from GPS readings to Datum Easter Island 1967.

Transformed (target) positions laid almost 150 meters east and about 70 meters south of its true locations on the archaeological map, defining a rhumb line near N64°W (transformed-towards-mapped positions) and a separation vector of about 160 meters. The apparent displacement for a point without performing any kind of transformation between both datum is about 295 meters, in a rhumb line near S81°W (WGS 84-towards-mapped positions) (figures 4, and 5).

The international geodetic registry only briefs for the zone the datum known as ‘Easter Island 1967’, with an astronomical origin associated to the ‘1924 International Ellipsoid’, and almost all geodetic applications and GPS equipment have built-in values that take into account the existing displacement between the center of this local datum and WGS 84. The mentioned registry only briefs three translation parameters (dX=211, dY=147, dZ=111), so the coordinates transformation process is accomplished by means of the simplified method of Molodensky[5], with an uncertainty of 25 meters for each of the resulting earth-centered Cartesian coordinates. The other values (rotation angles for the three Cartesian axes and a scale factor) needed to perform a more precise Helmert (Bursa-Wolfe) seven parameters transformation (figure 6), are not available for the ‘Easter Island 1967’ datum. Anyway, this would not solve the problem

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[5] A datum transformation method that only considers the 3D shifts between the centres of the involved ellipsoids.

because we are dealing with a completely different local datum[6].

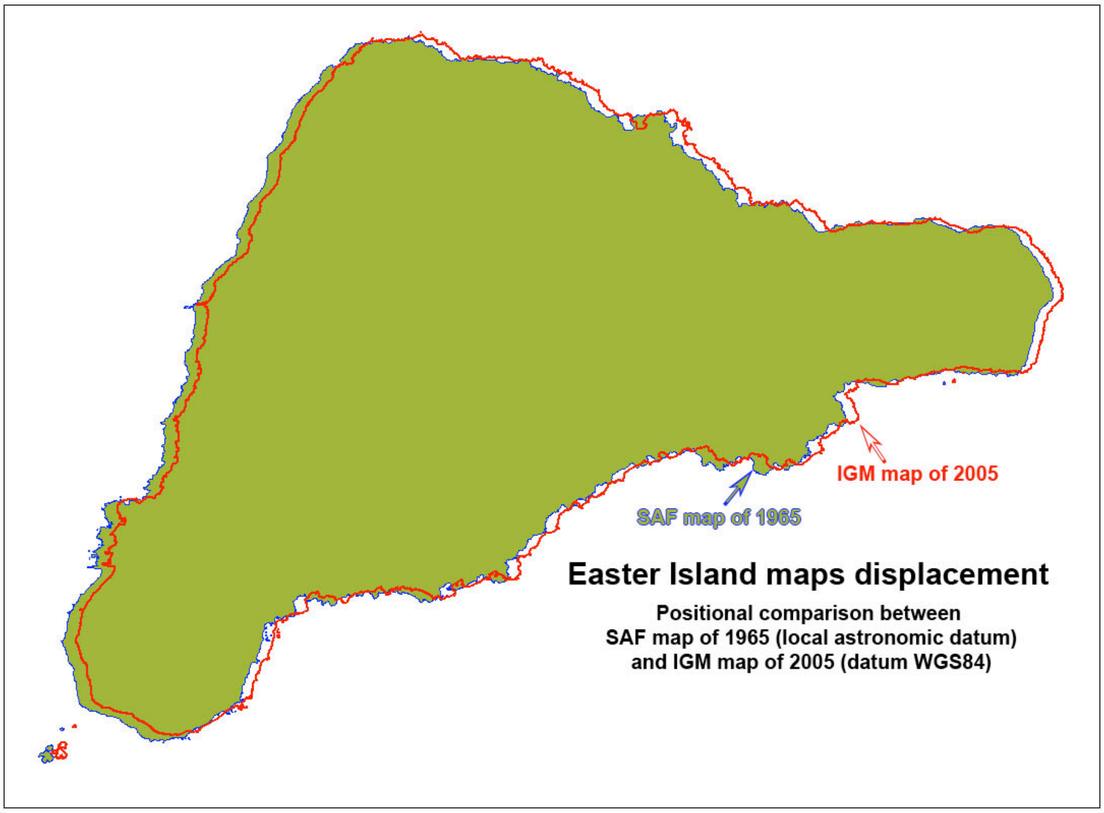

Figure 4: One island, two geodetic and cartographic positions.

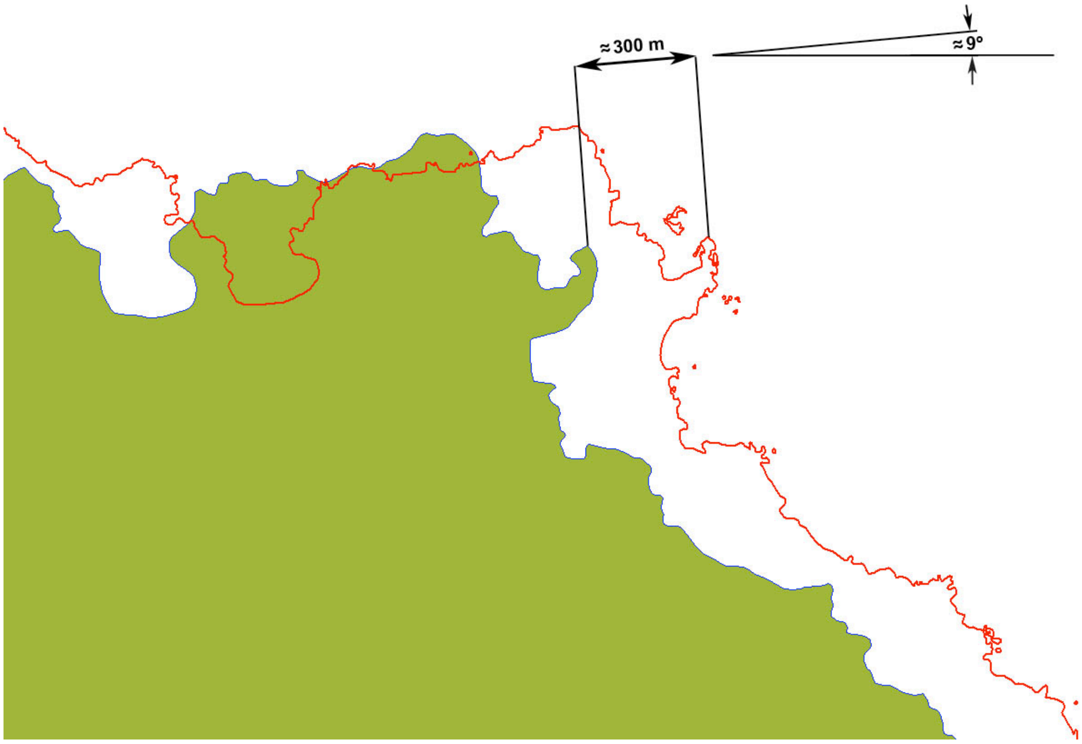

Figure 5: Enlargement of Figure 4, showing magnitude and relative orientation of mean displacement on the north coast.

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[6] At the Aereophotogrametric Service of the Chilean Airforce (SAF), no one seems to know about this datum, except for its astronomical origin and its association with the International Ellipsoid 1924 but, certainly, it is not the "Easter Island 1967".

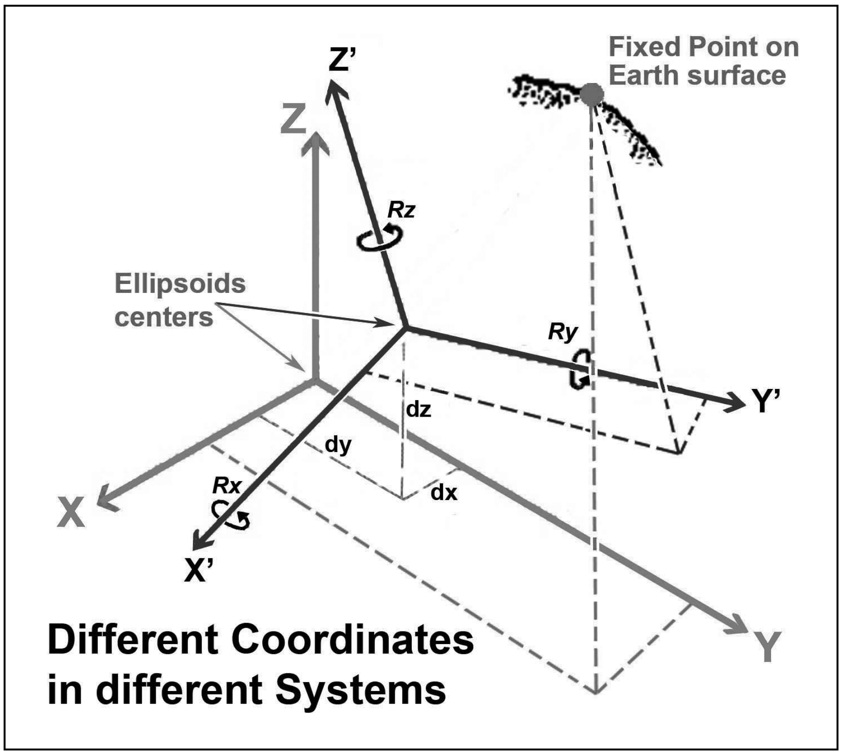

Figure 6: Graphic comparison of different coordinates in different systems for the same point.

The correct way to derive at least seven parameters needed to perform an analytical datum shift that will place the maps coinciding with the WGS 84 frame, starts by collecting precise DGPS-WGS 84 positions for a number of landmarks well distributed over the island, and with known precise coordinates for the local datum on which the mapping was georeferenced. Unfortunately, as we realized during the ground control fieldwork for the aerophotogrametric restitution in 1982, most of these old landmarks have been destroyed, and there are no vestiges of their precise locations. Finding some landmarks could solve the problem in an analytical way, for we know the local geodetic coordinates of a few of them. We are actually looking for resources to support the fieldwork needed to solve this problem.

On the other hand, a preliminary cartographic derivation of seven parameters, carried out by the authors based on ten carefully selected horizontal control points (nine along the coastal perimeter and one at the center of the island) gave, through a Helmert transformation, an average deviation of less than 10 meters at the control points, except for the eastern headland of the island (*Poike*) that showed a 40 meters deviation. The coordinates for each selected control point were obtained by digital means in UTM format; identifying them in both, the original cartography of 1965 and the new digital restitution georeferenced on WGS 84, made by the Instituto Geográfico Militar (IGM) in 2005, with the same aerial photographs taken by the Servicio Aerofotogramétrico de la Fuerza Aérea de Chile (SAF) in 1982 (see the island silhouettes in Figures 4 and 5).

With these results in mind, and supported by the fact that the archaeological information surveyed in each quadrangle is geometrically consistent and linked by ‘Connecting Traverses’ to permanent geographic and manmade features, present in the field and in the original maps, it was advisable to perform a differential transformation based in the digital correlation between homologous elements in both cartographies (1965 and 2005). In this way, blocks of archaeological features (sometimes approaching the size of a survey quadrangle or 6 to 7.5 square kilometers) are being moved to the new map locations, tied to homologous planimetric and geographic elements, thus assuring the preservation of its spatial geometry and correct georeference in datum WGS 84. The next step is to get DGPS positions over a number of well distributed points in each quadrangle/block, in order to evaluate the results.

CONCLUSIONS

Independently of the low precision inherent to a cartographic reading of coordinates, the result of our research and analysis confirms that the datum ‘Easter Island 1967’, considered for datum shift in the GPS equipments and related software *is not the one employed in the construction of the maps used for the Easter Island Archaeological Survey*. Therefore, researchers unaware of this crucial fact are using their GPS adjusted to the wrong Easter Island 1967 datum which is not the base of the SAF cartography used by the survey and are thus obtaining results with large unacceptable errors (wrong positions of up to 160 meters).

The situation we detected at *Poike* needs further study. The 40 meters deviation, shown at the selected control point in that area, may mean that some amount of rotation or displacement could be affecting the whole peninsula (or part of it), in relation to the rest of the island where much better results were obtained. The cartographic transformations needed there, will consider a single block adjustment of all the archaeological sites locations in the four quadrangles that cover *Poike*. All these sites are topographically tied to a main traverse, with extensions covering the entire peninsula.

Thus, considering:

a) That the original goals of the Easter Island archaeological survey were to identify, record and map the archaeological landscape of the island and other relevant aspects of the environment;

b) That for this purpose the original restitution of the island was enlarged twice its size;

c) That the size of a single point needed to symbolize an archaeological site covers approximately an area of 15 square meters;

d) The ±0.02 inches (±0.5mm = ±2.5 meters at 1:5000 scale) accepted as cartographic tolerance for 90% of horizontal positions by the USA National Map Accuracy Standards (NMAS);

e) The dimensional instability of paper maps due to changing conditions of humidity and temperature; and

f) the fact that the absolute method for calculating positions by pseudo-ranging, used in nearly all the GPS 'general purpose handheld' receivers, cannot model or eliminate the negative effects of the ionosphere, troposphere, etc., and therefore precisions of the calculated positions cannot be better than ±10 or ±15 meters,

it is clear that the differential cartographic transformation that we are carrying out to place the Easter Island Archaeological Survey maps into the WGS 84 Reference System, ensures that mapped positions will match the coordinates given by general handheld receivers, within a range covered by the resolution of this kind of equipment and by the limitations inherent to map reading procedures.

The seven Helmert parameters determined by our cartographic approach may also yield precisions within this sort of practical tolerance in the transformation of mapped sites coordinates to datum WGS 84. As mentioned above, another approach is needed for the *Poike* region which could even yield a different set of parameters for it.

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