

A LEGENDARY LOST CITY FOUND IN THE HONDURAN TROPICAL FOREST USING ERS-2 AND JERS-1 SAR IMAGERY

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ABSTRACT

Located in the remote, impenetrable and incompletely mapped rainforest of the Mosquito Coast, the legendary "Ciudad Blanca" of Honduras was never conquered by the Spanish. With time, it was slowly forgotten.

JERS-1 and ERS-2 SAR images are used to identify and to locate the lost city, a task made difficult due to the thick vegetation cover. Among the techniques used to detect artificial targets under forest cover, new Bayesian speckle filters, particularly suited for the restoration of a strongly, mixed textured scene, are used to enhance the SAR images.

In addition, radargrammetric techniques are used to produce a Digital Elevation Model (DEM) of the study area; and to fuse ERS and JERS information to allow easier visual identification of the remnants of "Ciudad Blanca" by visual photo-interpretation. Using the processed images, geocoded UTM spatio-maps of the region are also produced.

1. INTRODUCTION

In the eve of the 16th century, a great trading city was flourishing in what is known today as the Mosquito Coast, in North-Eastern Honduras. This city was first referred to under the double name of Xucutaco/Hueitapalan by Hernán Cortés already in 1526. After Cortés was told and reports in [1], it was an impressive city, comparable in population and in wealth to Mexico itself. Protected by the impenetrable rainforest of the "La Mosquitia" area, the city was further ignored by the conquistadores. With time, it was left to the jungle by its inhabitants, apparently already in the middle of the 16th century. Nevertheless, indigenous people still remember it as the legendary White City ("Ciudad Blanca"). The "Instituto Hondureño de Antropología e Historia" (IHAH) is conducting studies in the region. The village Las Crucitas (on the Aner River a few kms from the Wampú River) is established over one of the largest and most impressive archaeological sites of the region [2].

The project to accurately identify and locate the ruins of "Ciudad Blanca" has been initiated in November 1997, with the aim to contribute to return to Honduras and to mankind a bright page of history, and to put the site under protection of the due authorities.

2. SAR IMAGES ENHANCEMENT

Identification and location of the lost city has been carried out using two JERS-1 Level 2.1 amplitude SAR images and one ERS-2 SLC SAR image. As expected, such a task was made challenging by the presence of very thick vegetation, since the radar wave does not penetrate the whole vegetation cover of a tropical forest, even at L-band. Such a target was not expected to be directly visible by spaceborne SAR. However, the disturbances its presence causes to the natural arrangement of vegetation were expected to be somehow detectable in SAR images. To reach our goal new SAR image enhancement techniques had to be developed.

In presence of very strong texture, which is the case in our images with ancient ruins in a very dense tropical forest and in the presence of relief, it may be hazardous to make an assumption about the probability density function of the radar reflectivity. In this context, the A Priori knowledge with regard to the observed scene can hardly be an analytical first order statistical model.

However, satisfactory adaptability to such a variety and mixture of textures can be obtained by introducing a Maximum Entropy constraint on texture [3-4]. Under this assumption, we obtain the *Distribution Entropy Maximum A Posteriori (DE-MAP) filters for detected or complex SAR images* whose expressions are given in [5]:

Due to the nature of the targets we are interested in, and to the nature of their environment, these new speckle filters are particularly suited as image enhancement tool in the present application.

3. PROCESSING OF THE ERS AND JERS IMAGES

The available SAR images are: an ERS-2 Single Look Complex C-VV SAR image (October acquisition), and two JERS-1 Level 2.1 L-HH SAR images (February and July acquisitions). Since the quality of the SAR images per-processing contributes substantially to the accuracy of the final product, this aspect has been particularly stressed:

- Radiometric calibration of the SAR images is carried out, according to the ERS and JERS respective specifications.
- The ERS-2 SLC image is multilooked in azimuth to obtain a 4-looks amplitude image. This amplitude image

is resampled from slant to ground range, with a final pixel size of 20x20 m.

- The JERS-1 images are resampled to 20x20 m.
- Then speckle noise filtering is performed using the new DE-MAP adaptive speckle filters to restore scene textural properties and structural elements, without sensible loss in spatial resolution.
- A DEM is produced by radargrammetry, using the ERS-2 (incidence angle: 23.67°-26.51°) and JERS-1 (incidence angle: 35.12°-31.27°) SAR images, with a pixel size of 20x20 m (Fig. 1). In the present study, the horizontal DEM accuracy is better than 15 meters; the vertical DEM accuracy is better than 20 meters.
- In the original SAR images, relief is systematically displaced with regard to its true geographical location, due to the viewing geometry. Thus, the local geometrical corrections are performed, using the DEM.
- The radiometric corrections, accounting for the variation of effective scattering area with local slope and orientation, as well as for the variations in illumination conditions, are carried out, using the DEM. Effects of the variations of illumination on the image radiometry are evaluated using a physical backscattering model

4. CARTOGRAPHY OF THE SITE

At this point, a UTM/WGS84 spatio-map is produced (Fig.2). The grey levels in this map are obtained by Bayesian fusion of the filtered, geocoded, radiometrically corrected and geo-referenced SAR images [6].

5. CIUDAD BLANCA UNVEILED

First of all, we identified already known and documented sites in our SAR dataset. For instance, the site known as "Las Crucitas I" [2] is shown in the stereoscopic ERS-2/JERS-1 SAR images (Figs. 3-4). This site is one of the many archaeological sites that compose "Ciudad Blanca". The unfiltered images are shown in Fig. 3. The enhanced images are shown in Fig. 4. The features that are visible on this stereoscopic image correspond satisfactorily with the map of the site published by Lara-Pinto and Hassemann [2]. Similarly, a number of other already documented sites, as well as numerous minor artefacts that are probable ruins scattered in a *ca.* 20x20 km wide area near have been identified by a careful examination of the processed images. Nevertheless, an important finding was made during this systematic examination. Covering a 3.0x3.5 km wide area in one of the denser part of the forest (and close enough to "Las Crucitas" to be connected to the sites that are already documented there), the ruins of a vast complex of important structures are visible in the images. The stereoscopic ERS-2/JERS-1 SAR images in Figs 5-6 illustrate the most interesting part of this area, including what is very probably a vast ceremonial center. The unfiltered SAR images are shown in Fig. 5. The enhanced images are shown in Fig. 6.

It is noticeable that a systematic bibliographic research conducted in Honduras, in the USA and in Europe from January 1998 to May 1998 showed that this site has not been documented until now. The last report of a place structurally similar to this one in this area dates back to 1544, when a Spanish missionary was guided there by local people.

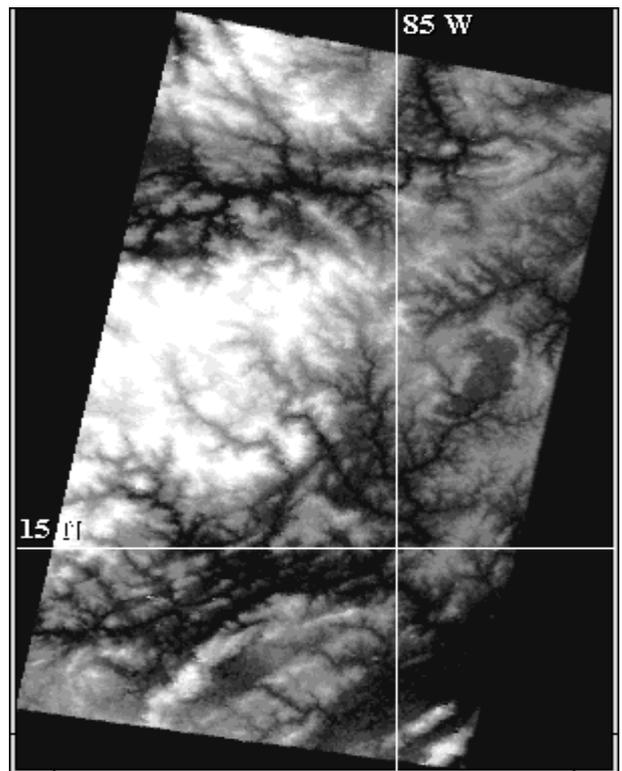


Figure 1: DEM obtained by ERS-2/JERS-1 radargrammetry. Area shown: 59 x 81 km.

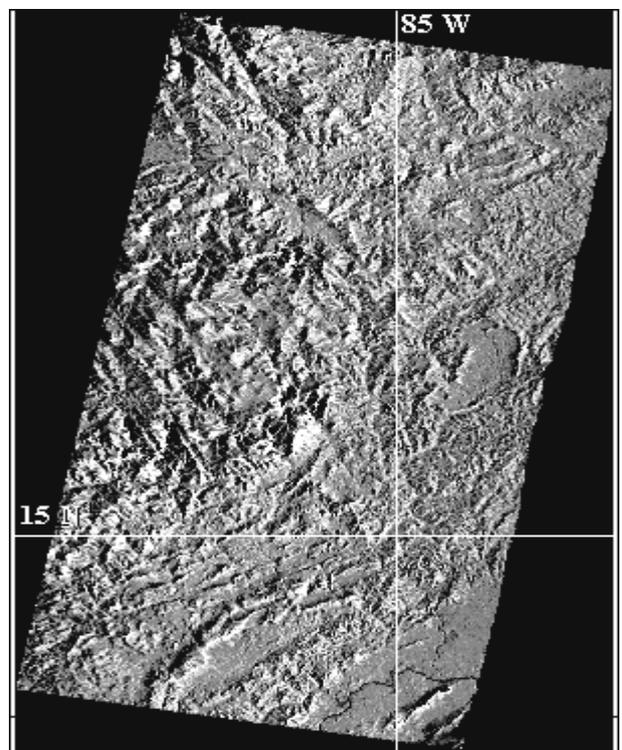


Figure 2: UTM (WGS84) map of the "La Mosquitia" area around the site of Ciudad Blanca. Area shown: 59 x 81 km.

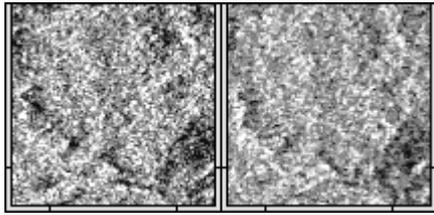


Figure 3: The documented site of Las Crucitas I. Unfiltered SAR data. Area size: 2x2 km. (Left: ERS; right: JERS-1).

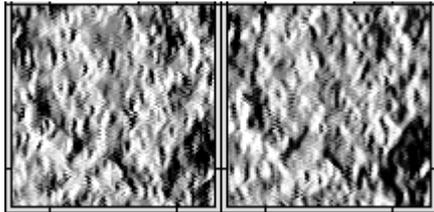


Figure 4: The documented site of Las Crucitas I. DE-MAP Filtered. Area size: 2x2 km. (Left: ERS; right: JERS-1).

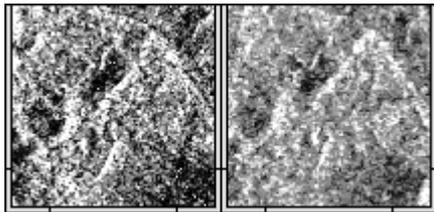


Figure 5: The great undocumented site found. Unfiltered SAR data. Area size: 2x2 km. (Left: ERS; right: JERS-1).

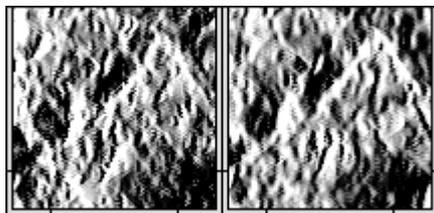


Figure 6: The great undocumented site found. DE-MAP Filtered. Area size is 2x2 km. (Left: ERS; right: JERS-1).

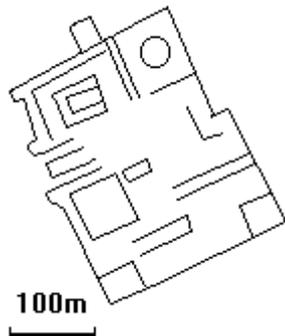


Figure 7: Map of the probable ceremonial center found in this study.

Fig. 7 is an enlargement of the important structures located in the upper-left quadrant of Figs 5 and 6, made by photo-interpretation of these images. From the elevation map and the shadows observed in the images, one may infer the presence of a pyramid (or a high square-shaped structure) in the north-western part of the area represented in Fig. 7.

6. CONCLUSION

The legendary lost city "Ciudad Blanca" has been identified in ERS-2 and JERS-1 SAR data. Its ruins are scattered over a wide area (ca. 20x20 km) in "La Mosquitia", Honduras. Some already documented major centers have been identified, and an important still undocumented complex of ruins, apparently the most important in the area, has been discovered using the DE-MAP enhanced SAR images. Additional archaeological research in the region may confirm that its peoples were an important link between pre-Columbian cultures in North and South America.

It is noteworthy that, although C-band SAR is generally not expected to detect structures under dense tropical forest, it has proven here as efficient as L-band SAR to identify the ruins of "Ciudad Blanca". Given the density of the rainforest in "La Mosquitia", it is even unlikely that L-band waves could completely penetrate through the forest cover. In fact, SAR detection of the ruins is indirect: we detect merely the perturbations caused by the ruins to the structure and to the density of the forest cover.

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