Chapter 11
The Use of Multispectral Imagery and Airborne Synthetic Aperture Radar for the Detection of Archaeological Sites and Features in the Western Maya Wetlands of Chunchucmil, Yucatan, Mexico

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Abstract This case study presents the results of an extensive remote sensing survey testing the capabilities of multispectral and Synthetic Aperture Radar data to detect ancient Maya settlements in the seasonally inundated near-coastal region of northwest Yucatan. The results are compared to similar recent studies published by researchers working in the southern Maya lowlands. It is concluded that seasonal and regional variation across the Maya area precludes universal application of a singular remote sensing technique using these and similar platforms. Instead, specific climatic, seasonal, and physiographic context must be considered in the selection of a remote sensing data set. For multispectral data, spectral contrast, spectral resolution, and temporal resolution appear to be more critical for site detection than spatial resolution. For the AirSAR polarimetric data, it is concluded that the L-band (rather than the highly anticipated P-band) resulted in a better correlation between positive returns and monumental architecture within the forest canopy. Yet, the C-band AirSAR DEM appears to have the broadest application in Maya archaeological survey, especially when combined with other remote sensing data sets.

Keywords Maya • Remote sensing • Landsat • Multispectral • Synthetic aperture radar • AirSAR • Chunchucmil • Vegetation • Seasonal wetlands

11.1 Introduction

Archaeological remote sensing has a long (yet mixed) history in the Maya area, with many pioneering efforts advocating the wide applicability of new technologies, often followed by published studies critiquing the practical applications of these same technologies (e.g., Adams 1982; Pope and Dahlin 1989). With each additional study, researchers refine our knowledge of both the capabilities and limitations of available remote-sensing platforms for the field of archaeology. The results of the

D.C. Comer and M.J. Harrower, *Mapping Archaeological Landscapes from Space*, SpringerBriefs in Archaeology, DOI 10.1007/978-1-4614-6074-9_11,

following case study from Chunchucmil, Yucatan, when placed within the context of our seemingly endless effort to peer below the vegetation blanketing southern Mexico and northern Central America, suggest why some projects seem to have greater success than others when utilizing the same technology.

11.2 Multispectral Remote Sensing of the Maya Area

Early use of multispectral Landsat data to directly detect ancient Maya features initially resulted in a better understanding of the road systems connecting ancient capitals to their secondary centers. Folan et al. (1995: 277–283) found that causeways could be detected as linear peaks in the infrared bands, indicating lines of vigorous plant growth through low swampy areas. The authors also found that those pixels combining to form indications of "dryness" (using a tasseled cap transformation [Lillesand and Kiefer 2000: 523]) could differentiate causeways from inundated terrain (1995: 279). Subsequent studies by NASA archaeologist Tom Sever (1998) verified the utility of this approach for the detection of ancient road beds. But specific spectral reflectance values directly indicating the presence of habitation sites beneath the forest canopy remained elusive.

A recent publication by Saturno et al. (2007) briefly discussed the limitations of Landsat imagery for the detection of ancient Maya archaeological sites, and indicated that the sensor's spatial resolution (30 m multispectral, 15 m panchromatic) was its greatest constraint. Instead they examined the potential for Very High Resolution (VHR) multispectral imagery (IKONOS). The IKONOS platform produces 4 m multispectral (3 bands visible and 1 near-infrared) and 1 m panchromatic data sets. In the pan-sharpened multispectral data, the authors observed a spectral reflectance indicating canopy stress over known Maya centers in the San Bartolo region. Upon further investigation, this was found to correlate with previously undocumented sites. The researchers concluded that VHR multispectral imaging was successful in predicting the locations of archaeological sites, from large centers to small tertiary settlements, and that the imagery "had the potential completely to revolutionize archaeological survey in the tropics by dramatically reducing the time involved in systematically covering vast areas" (2007: 149).

Yet, an attempt by Garrison et al. (2008) to replicate this process in other areas of the Maya lowlands demonstrated that archaeological remote sensing has not yet found that surveyor's panacea envisioned by Saturno. Garrison and his team found that the IKONOS "vegetation signature" observed by Saturno is weak to non-existent over other major Maya centers in neighboring regions (e.g., Ceibal). Meanwhile a spectral response even stronger than that noted by Saturno was identified by Garrison as a false positive reading (only two platforms where the satellite imagery indicated a major center in the Sierra de Lacandon).

The conclusion of Garrison and his colleagues was that "local climate, geology, hydrology, topography, pedology, and vegetation" differs significantly from region to region, making broad application of Saturno's observations at San Bartolo problematic (Garrison et al. 2008: 2770). Garrison also notes the problems inherent in seasonal climatic variations when attempting to compare reflectance values across images taken at different times of the year.

11.3 Multispectral Remote Sensing of the Chunchucmil Region

The site of Chunchucmil is located in the northwest corner of the Yucatan peninsula, Mexico. First identified in the mid-1970s by the *Atlas Arqueólogico del Estado de Yucatán* (Garza and Kurjack 1980), this metropolis is comprised of several 1,000 house mounds and dozens of temples jutting out of the relatively planar landscape that is the Yucatecan karstic plains physiographic region.

The lack of topographic relief, combined with the lowest rainfall total in all the Maya lowlands, makes this scrub forest ideal for the application of remote-sensing techniques for archaeology, especially when compared to the lush tropical jungles of the southern Maya realm. Chunchucmil was readily detected by the Atlas project using high-resolution stereoscopic aerial photographs. From these photos, they were able to describe the site center and map a portion of the residential core (Garza and Kurjack 1980; Vlcek 1978; Vlcek et al. 1978) using limited field verification.

Decades later, our Pakbeh Regional Survey subproject (1999–2005) decided to build upon the successes of the Atlas project by applying multispectral imaging to our study of Chunchucmil's overall size, layout, and regional settlement pattern. We began by examining nearly three decades of multispectral Landsat data, looking for images that clearly differentiated the urban core of Chunchucmil from its natural surroundings.

Since seasonality dramatically affects the surface configuration of the region, we acquired both dry-season and rainy-season images for all decades of the Landsat mission. We found that multispectral images following early heavy rains were infinitely more valuable than those images taken during the height of a drought. In July of 1999, when a tropical storm stalled over this corner of Yucatan, our project was present to note the seasonal wetlands encroaching upon the sites center, with only the archaeological mounds and other cultural features protruding from the temporary inundation. The water quickly receded, but the effects on regional vegetation patterns were pronounced.

By the end of July, the secondary growth covering any partially cleared archaeological site burst into life. Even the most modest residential mounds were composed of anthropogenic soils that supported green leafy vegetation while the surrounding terrain was filled with either still-receding flood waters or recovering low-lying grasslands. Bands 4 and 5 of Landsat 7 (near- and mid- infrared) highlighted not only the urban core of Chunchucmil, but also several large secondary sites previously noted by the Atlas project (Fig. 11.1).

In addition to using the infrared bands, we were able to generate new bands using the same tasseled cap transformation that was so beneficial to previous Maya scholars. The algorithm generates three new bands characterized as "brightness,

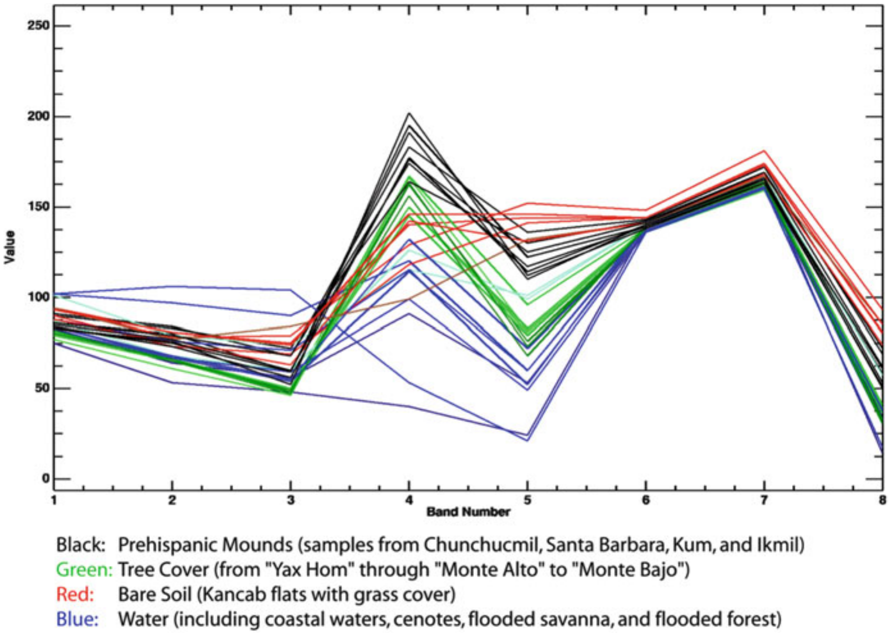

Fig. 11.1 Spectral plot of selected pixels from Landsat 7 ETM + imagery of NW Yucatan, July 1999, showing the greatest spectral contrast in the near- and mid-infrared bands (4 and 5)

greenness, and wetness" (Lillesand and Kiefer 2000: 523). All of the archaeological sites that could be detected in the multispectral imagery (Fig. 11.2) share the characteristics of being bright (broken limestone surfaces), green (early lush vegetation), and relatively dry, when compared with surrounding natural features such as mature canopy (blue-green in this imagery), bare rocky soil or barren fields of dead grass (red), or inundated *bajos* (deep blue).

We then used the Landsat imagery to estimate the size of ancient Chunchucmil. It was concluded that the most densely settled portion of Chunchucmil covered an area of roughly 25 sq km, with a more sparsely populated suburban zone that increased this number to nearly 64 sq km (Hixson 2005). Years later, pedestrian mapping transects revealed that the actual settlement density of Chunchucmil was consistent with the multispectral remote sensing estimates (Hutson et al. 2008).

We next established six targets within the western seasonal wetlands to test the sensor's capability of detecting secondary or tertiary settlements beyond the urban core of Chunchucmil. All six resulted in the discovery of previously undocumented settlements, from secondary ceremonial centers to rural farmsteads and seasonal camps (Hixson 2011).

The lessons learned during the multispectral remote-sensing surveys of Chunchucmil revolve around seasonality and synchronic on-the-ground observations. In an area where tidal fluctuations, local rainfall, surface drainage, and minor

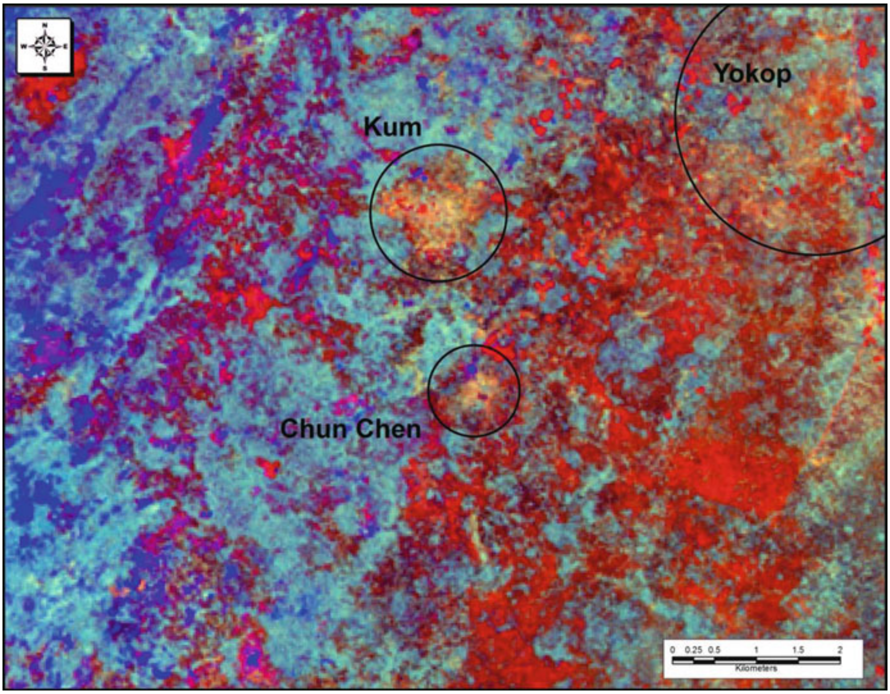

Fig. 11.2 Tasseled cap transformation of Landsat 7 ETM + imagery from July 1999, highlighting the western regional sites of Kum, Chun Chen, and Yokop. *Yellow* = Bright, Green, and Dry

topographic rises dramatically affect the surface configuration (and potential ancient settlements), the selection of remotely sensed imagery based upon specific and observable seasonal conditions appears to be crucial.

Only one Landsat image out of dozens proved to clearly differentiate "site" from "non-site". This supports Garrison's preliminary conclusions regarding the importance of regional and temporal variation in climate and ecology (Garrison et al. 2008). Our research at Chunchucmil suggests that one must find the imagery that precisely captures the time of year when vegetation is under the *proper* stress to highlight different surfaces through elevated spectral contrast. If the region is uniformly dry, the result will be "dry rocky mounds" against "dry rocky ground". If the region is uniformly wet, the imagery will be blanketed by a drape of impenetrable greenery.

The Chunchucmil data also indicates that Saturno's focus upon VHR (very high *spatial* resolution) imagery is misplaced. The 30 m Landsat TM data was more than sufficient to differentiate site from non-site under the proper regional and seasonal conditions. In fact, the addition of the mid-infrared band (LS-band 5 – not available on IKONOS) was critical to the application of the tasseled cap transformation. Even without the tasseled cap transformation, archaeological sites around Chunchucmil were clearly indicated in a contrast stretch of bands 5,4,2 of the Landsat data (Fig. 11.3). But most importantly, Landsat's vast archive of images extending back

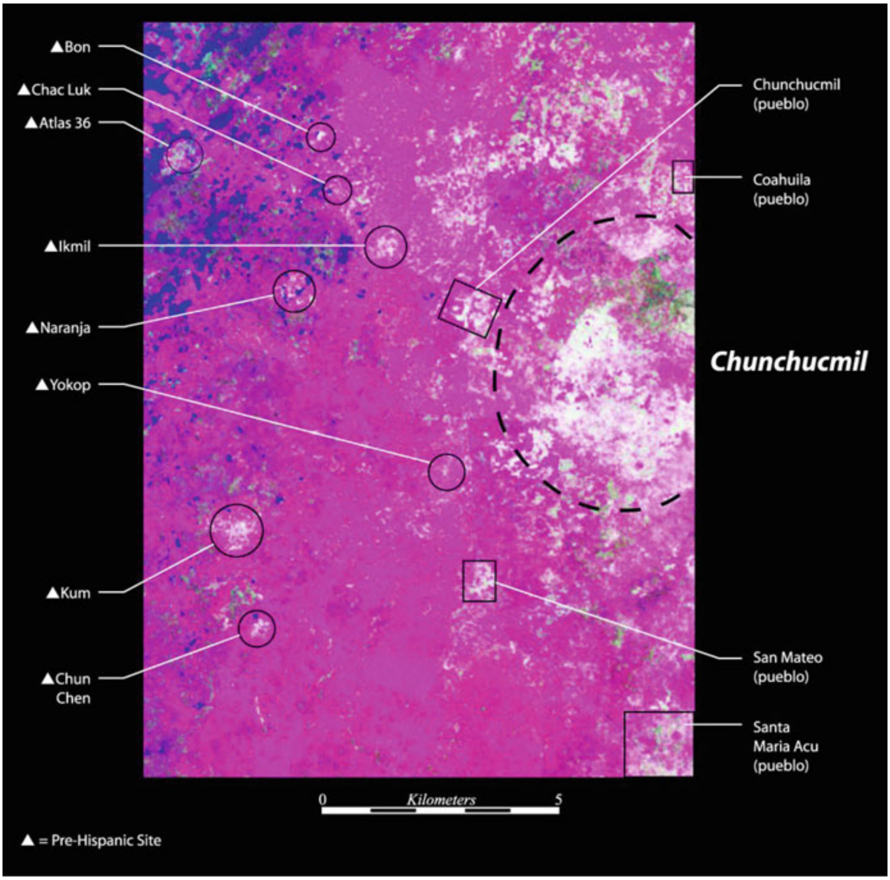

Fig. 11.3 Landsat 7 ETM + image (bands 5,4,2) from July of 1999, histogram equalization stretch, highlighting Chunchucmil and its western hinterland. Peaks in all three bands (mid-infrared, near-infrared, and visible green) result in white pixel clusters over archaeological sites and modern villages

to the 1980s, with regular and repeated passes over the entire region, provided greater *temporal* resolution, allowing for the precise selection of an image based upon specific seasonal conditions.

11.4 Synthetic Aperture Radar Survey of the Chunchucmil Region

The Chunchucmil project, along with over a dozen other programs, also participated in the "AirSAR Mesoamerica" campaign (Blom et al. 2003). Collectively, we decided that the experimental use of the P-band would be most beneficial, as it has

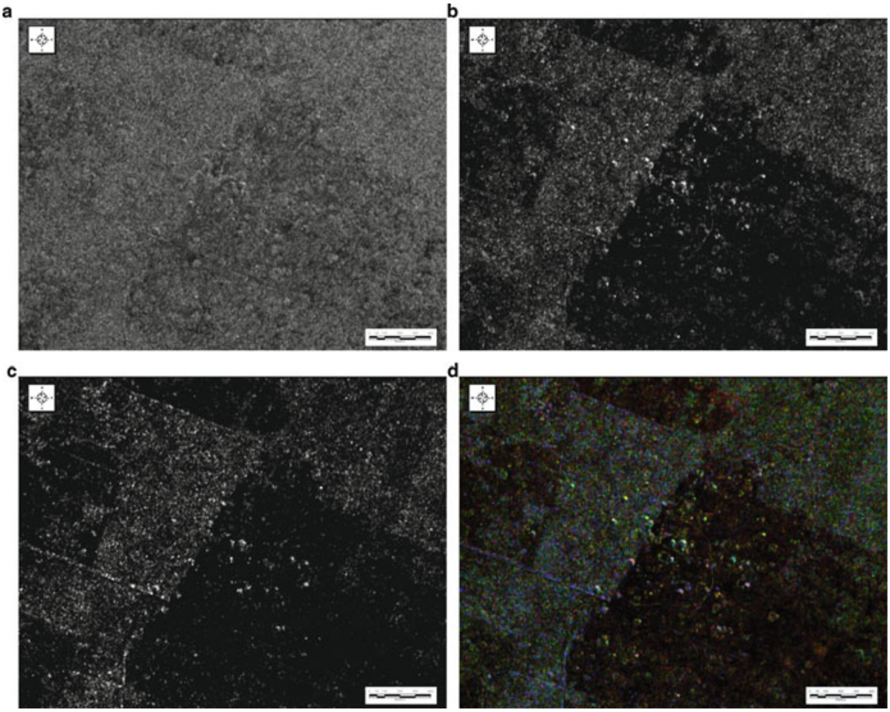

Fig. 11.4 AirSAR data of the site center of Chunchucmil. (**a**) C-vv; (**b**) L-hv; (**c**) P-hv; (**d**) L-hh, L-hv, and P-hv (in RGB color space)

the longest wavelength and therefore the greatest likelihood of penetrating the dense canopy of southern Mesoamerica for the detection of archaeological features (Pope et al. 1994). The instrument was flown in "TOPSAR" mode, generating both fully polarimetric imaging data and a C-band DEM (see Chapman and Blom, this volume). The AirSAR instrument flew over the Chunchucmil region in four swaths measuring approximately 50 km long by 10 km wide in March of 2004. The resulting data covers roughly 2,000 sq km.

The AirSAR Mesoamerica campaign originally had high hopes for the P-band. We were finally going to "pierce" the forest canopy and receive backscatter signals from the actual ground surface. At the AirSAR Mesoamerica roundtable, held 1 year after deployment, none of the participants (from Tikal to Chunchucmil) achieved this outcome. Since that time, only one publication has offered a newly discovered site based upon the AirSAR Mesoamerica data (Garrison et al. 2011; using the C-band DEM rather than the P-band imaging data). The Chunchucmil project, however, appears to have provided the best results to explain the failings of the P-band to live up to our hopes.

Figure 11.4 illustrates the differences between the C-band, L-band and P-band results for the site center of Chunchucmil. Note that at the time of data acquisition

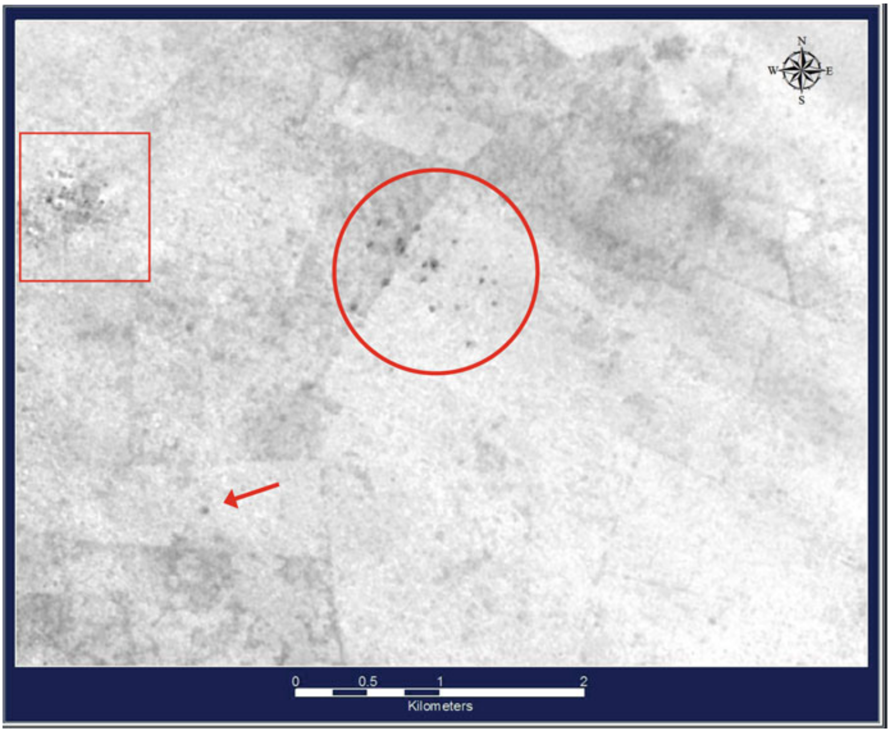

Fig. 11.5 AirSAR DEM (color inversed) showing the tight cluster of pyramidal mounds within the 1 sq-km site center of Chunchucmil, with one outlier known as “the south group.” The modern village of Chunchucmil appears in the *upper-left*

the eastern half of the site center was relatively denuded of vegetation, while the western half was in modest forest with a relatively dry 15-to-20 m-tall canopy. The C-, L- and P-bands all detected the tallest pyramids, even within the forested western section of the site center, however the C-band (the shortest wavelength, at 6 cm) and the P-band (the longest wavelength, at 68 cm) also provided false readings that could have been confused for architecture without previously ground-truthed data sets.

The L-band (at 24 cm) provided a near perfect correlation between positive readings and monumental architecture within both the cleared and the forested portions of the site. The longer P-band *did* pierce the canopy, but also provided direct or double-bounce backscatter readings for various natural structures beneath the canopy. Meanwhile, the C-band provided an abundance of returns on smaller natural features of the upper canopy or lower undergrowth. The L-band provided a randomly oriented scatter off the general backdrop of the dry forest canopy, thus allowing the remote-sensing software to highlight where there were sharp anomalies in the canopy itself (backscatter off of the pyramids or the largest trees that grow upon them) without being confused by naturally occurring surfaces beneath the canopy or at its crest.

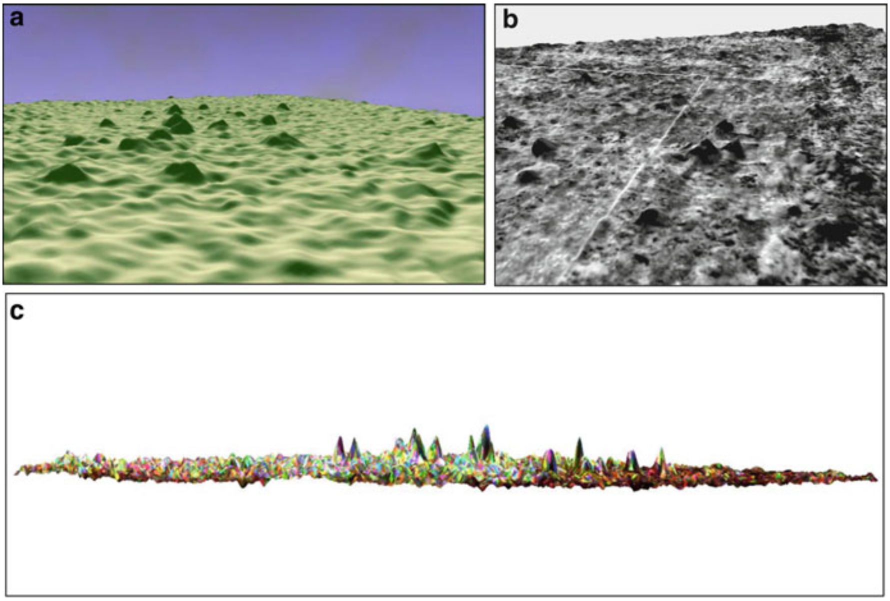

Fig. 11.6 AirSAR digital elevation model of Chunchucmil (**a**) AirSAR DEM perspective view of the site center facing east; (**b**) AirSAR DEM with an image drape of INEGI orthorectified aerial photos, perspective view of the site center facing southeast; (**c**) AirSAR DEM profile view of the site center, Chunchucmil. Vertical scale amplified

Figure 11.5 illustrates the AirSAR C-band DEM of Chunchucmil's site center. The largest architecture is tightly clustered within the central 1 sq km, matching all published estimates for the urban core. Other smaller pyramids can be found in the imagery, but it is clear that Chunchucmil had a tightly clustered nucleus of monumental architecture. A perspective view of the DEM illustrates the ability of the sensor to detect mounded architecture within both cleared fields and secondary forest (Fig. 11.6a). By merging this DEM with aerial photographs (Fig. 11.6b), not only do the pyramids "pop" out of the imagery, but so do the quadrangular arrangements associated with each pyramid. When viewing the DEM in profile (Fig. 11.6c) the monumental architecture of Chunchucmil appears as a normalized curve, highlighting the site's tendency towards a centralized settlement pattern even within the site core. This DEM also led our survey crew to discover a previously undocumented archaeological site outside of the town of Dzidzibalchi, Yucatan, where (in a situation similar to Garrison et al. 2011) large natural hills had been heavily modified to act as foundations for architecture – causing this secondary settlement to appear like a large built city in the AirSAR DEM. The DEM was also used in concert with the multispectral imagery discussed above to locate a Middle Preclassic ballcourt site far into the wetlands west of Chunchucmil (Hixson 2011).

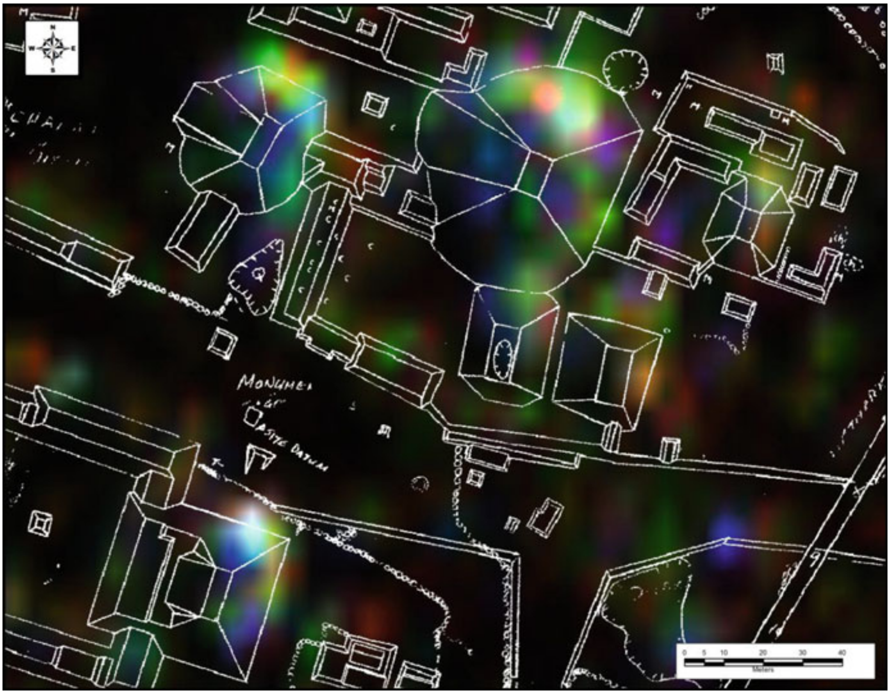

Fig. 11.7 AirSAR bands L-hh, L-hv, and P-hv (in RGB color space) of the pyramidal structures surrounding the site center datum, overlaid with the georeferenced hand-drawn field maps

Another important observation for the detection of cultural remains using AirSAR is the benefit of polarization and the prevalence of double-bounce returns. The bands that returned the best data for the detection of ancient features of Chunchucmil's site center were those that were sent with horizontal polarization and received through a vertical filter (specifically L-hv). Figure 11.4d provides a false color composite of the site center using three bands of the AirSAR data (L-hh, L-hv, and P-hv) and Fig. 11.7 overlays our hand-drawn map of the site center with those same three bands. The strongest returns from the L-hv band (in green) cluster at the northeast corners of each pyramid's basal platform. This highlights two factors influencing the results. First, the look angle was originating from the northeast (peering southwest). Thus, the northeast sides of structures produced the strongest returns, while the southwest sides of structures remained dark (within a "shadow effect"). This is also reflected in the DEM (Fig. 11.6a) where elevation details are most accurate on the northeast slopes of structures, while the SAR "shadow effect" creates false tailings on the southwestern slopes. Second, the highest returns in the cross-polarized L-band data from the bases of pyramids indicate a strong "double-bounce" scenario (see Chapman and Blom, this volume).

In the end, the AirSAR platform has proved an excellent resource for locating a major ancient Maya site center within the semi-arid scrub forests of northwest

Yucatan. While the Pakbeh project already knew the locations of all major structures within the site center of Chunchucmil prior to the deployment of the platform, this test of the sensor allowed a more synoptic view of the region. Since the AirSAR swaths covered approximately 2,000 sq km, a thorough review of the DEM suggests that no other major Maya centers exist within this remote-sensing survey area. Nearly all monumental architecture resides within a centralized 1 sq km (the site center of Chunchucmil). This places Chunchucmil at the apex of its regional settlement hierarchy, potentially dominating a much larger area than many proposed pre-Columbian polities. Plus, AirSAR has demonstrated the lack of any first- or second-tier competitors which are relatively common in other lowland Maya regional hierarchies.

11.5 Conclusions

Within the seasonal wetlands of the northern Maya lowlands, spectral contrast is at its height following the first heavy rains of the season. While this meteorological situation cannot be predicted, it is ideally observed through remote sensing platforms that capture images over a repeated interval (such as searchable Landsat archives). Multispectral platforms with a high temporal resolution result in greater likelihood of useful returns than high spatial resolution scenes from a tasked platform. Furthermore, we conclude that high spatial resolution is not necessary for site detection. Rather, spectral resolution and heightened spectral contrast must be emphasized in the selection of remote-sensing platforms and images.

Similarly, while the AirSAR platform produced a dramatic image of the site center of Chunchucmil, its utility was limited beyond the monumental core due to the lack of contrast between seasonally dry *bajos* and perennially dry uplands. Synthetic aperture radar excels at differentiating inundated surfaces in seasonal wetlands (Pope et al. 1994, 2001). But the data from the height of the dry season at Chunchucmil showed that structural contrast is reduced under extremely arid conditions. It is the recommendation of this project that future SAR missions over seasonally inundated terrain fly during the rainy season.

Finally, from aerial photography to Landsat to AirSAR, these and other remote-sensing technologies are often best used in concert, either merged, layered or draped together within an image-processing or GIS package. Or they can each serve as a preliminary check upon the other before the absolutely vital step of field verification (see Corbley 1999).

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