Detection and Identification of Archaeological Sites and Features Using Radar Data Acquired From Airborne Platforms

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Introduction

The Department of Defense DoD and Department of Energy (DoE) are required to identify and protect archaeological and cultural resources on land they control. At present, 80% of DoD land alone is unsurveyed. Present survey methods are very slow and expensive. Accidental discovery of critical sites (e.g. burials) can have very significant operational impacts. The Jet Propulsion Laboratory of the National Aeronautics and Space Administration (JPL/NASA) and Cultural Site Research and Management (CSRM) are partnering to develop the use of synthetic aperture radar (SAR) deployed from aerial platforms to find and characterize archaeological sites. The Department of Defense (DoD) Strategic Environmental Research and Development (SERDP) program is sponsoring this research. San Clemente Island, approximately 60 miles off the coast of southern California, near San Diego, will be the test area for the research. Dr. Ronald Blom of JPL/NASA and Dr. Douglas Comer, Principal of CSRM, are co-Principal Investigators for the research.

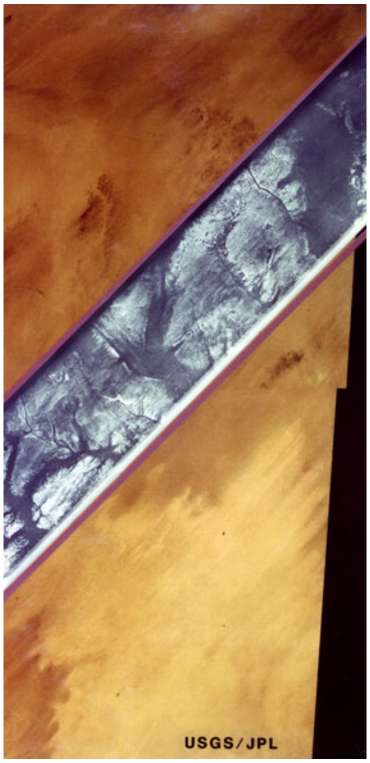
Previous research has established that multi-band and multi-polarization radar interacts in detectable ways with phenomena that are strongly associated with human occupation and activities. Human occupation, more specifically, typically produces or is associated with features and materials with dielectric properties (e.g., water and carbonaceous deposits), regular geometric shapes, etc. anomalous to the natural topography and vegetation. Prior studies have also shown that radar can also be used to characterize environmental conditions and variations in ways that can be used to model and therefore predict archaeological site and feature distribution. Multi-band and multi-polarization radar clearly holds the potential to be employed as a powerful tool for directly detecting and identifying archaeological sites and features. To realize this potential, the current research will establish protocols for:

- Synthetic aperture radar (SAR) data collection, e.g., look angle and mode.
- SAR data processing and image production.
- SAR image post-processing.
- Nested analytical protocols.
- Optimal use of SAR bands, polarizations, and combinations of these.
- Corroborative use of multi- and hyper-spectral data sets.
- Spatial modeling of archaeological sites and features.
- Procedures for incorporation into, and analysis with a GIS.

Background

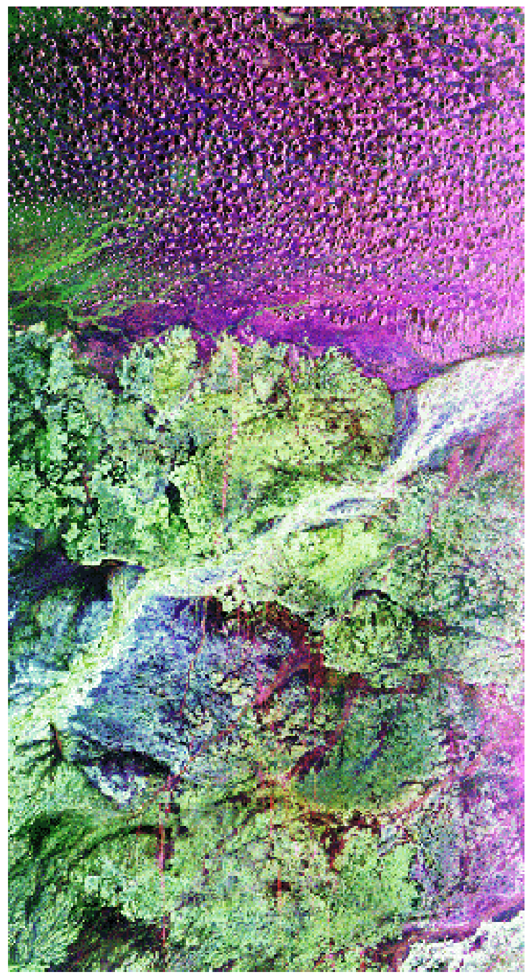
Widely publicized applications of radar to archaeological research have demonstrated the utility of SAR. In the early 1980s, SAR carried by a satellite was used to discover “radar rivers” in areas of the Sahara now covered by desert. These desiccated riverbeds, presently filled with sand, provided clues to the locations of ancient occupations in the region (see Fig. 1).

Figure 1 "Radar rivers" discovered with SAR



Subsequent applications of synthetic aperture radar, enhanced by multi-band and multi-polarization capacity, were tested independently by the co-principal investigators for this research, and by research team member Derrold Holcomb. Ronald Blom used radar and multi-spectral sensors deployed from space over Arabia to find routes and sites associated with the ancient trading city of Ubar (Fig. 2). Derrold Holcomb, an expert in the enhancement, and interpretation of images produced by radar, used synthetic aperture radar in hyper-arid areas of the Taklamakan Desert in China to find landscape features and sites associated with the Silk Route. Because radar is highly sensitive to regular geometry, even if backscatter is reflected from topographic irregularities only centimeters high, Douglas Comer could use multi-band and polarization synthetic aperture radar carried by the space shuttle Endeavour to detect the pattern comprised by the structures associated with the ancient trading city of Petra, in southern Jordan (see Fig. 3). This could be done even though remains were almost completely obliterated in some areas. Disturbance of structures was severe enough that they had remained undetected during surface surveys of the area. Wall sections could be seen standing in certain locales, but large lengths of walls had been reduced to rubble. Radar could detect the pattern created by linear arrangements of wall sections and rubble, even though these structures were not noticeable in aerial photographs. Comer also determined that backscatter could be affected by features of less than pixel size in ways that would produce a distinctive, pixel-sized signature for certain kinds of archaeological features (in this case, semi-subterranean chambers, see Fig. 4).

Figure 2 Trading routes (thin purple lines) converging at Ubar



Finally, he found that radar sensitivity to both gross and fine topographic variation could be used to

Figure 3 Foundation pattern detected even though some portions were obliterated

characterize landscapes in which archaeological sites occur in ways related to ancient human occupation of those landscapes. (Fig. 5)

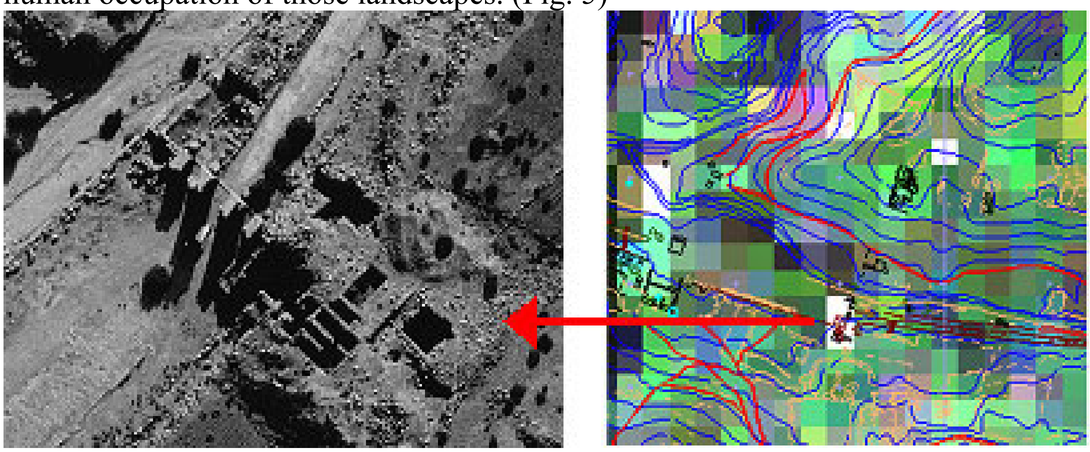


Figure 4 Subpixel detection of semi-subterranean chambers

Technical Approach

Radar instruments operate in bands of varying wavelengths that interact with objects differently depending upon density, size, shape, and characteristics that affect electrical conductivity, including water content. In general, radar backscatter is most affected by topography (even topography as fine as surficial roughness), dielectric properties, and vegetation. Not only backscatter, but also penetration, is different for different bands and polarizations: Lower frequency data (P and L-Band) can penetrate soil and vegetation. Higher frequency (C and X) bands are reflected more readily from smaller features (like vegetation) and are more sensitive to surface microtopography (see Fig. 6). Each wavelength is especially sensitive to objects that are on the same size scale as the wavelength. Because longer wavelengths can penetrate vegetation and certain types of dry soil cover, they can potentially detect larger objects, water, or materials containing water below. Shorter wavelengths detect fine variations in texture. All bands can be polarized to be transmitted and received both horizontally and vertically. Polarization can fine-tune radar sensitivity to objects of various sizes and shapes.

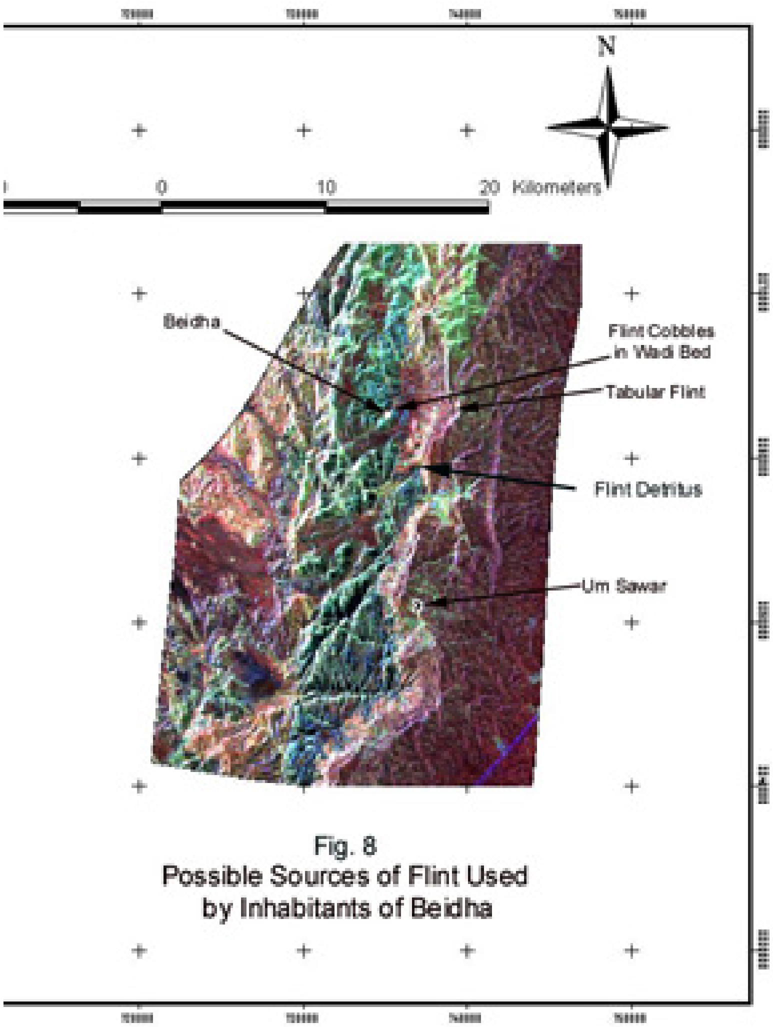


Figure 5 SAR used to characterize geological phenome sandstone, limestone) and micro geography (flint depo

Especially important is radar sensitivity to geometry. With the appropriate post-processing of imagery produced from radar data, regular geometry, which is a hallmark of humanly contrived features, can be detected at even the sub-pixel level, as Holcomb and Comer found. The radars used in the current research can also be operated in an interferometric mode to produce Digital Elevation Models (DEMS). DEMs, which themselves provide extremely useful information to archaeologists, can further be used as a base map to orthorectify radar or other sensor images; that is, to remove or greatly reduce elevation-induced geometric and radiometric distortion of these images. The high-resolution topographic data can be extremely valuable in prediction of potential habitation sites in concert with the radar image data. All of this provides a tool kit that is admirably suited to detecting characteristics that are usually associated with archaeological sites: regularity of pattern, differences in soil composition and vegetation,

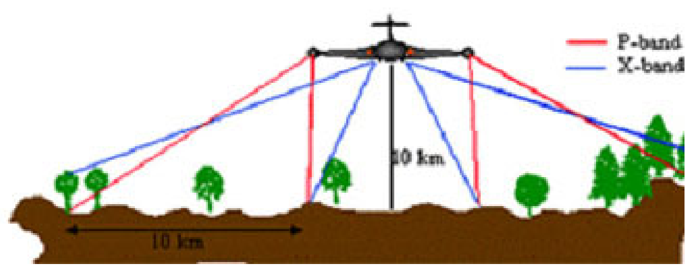


Figure 6 Differential penetration of SAR bands: here, P band penetrates tree canopy while X band is reflected by it

and topographic anomaly. This is because humans tend to alter the environment in ways that are often regularly patterned, and predictable.

Cultural Resource Management

In developing the protocols, it will be essential to produce an elegant fit with the practical objectives of the SERDP funding organization. These practical objectives are essentially identical with the objectives of all public land management agencies in regard to the protection of cultural resources. Specifically, land management agencies must comply with federal, state, and local legislation and regulation that require consultation prior to initiating activities that might adversely affect sites that might be eligible for inclusion in the National Register of Historic Places, or listing on specific state or local registers of important historic or archaeological sites. It is prudent, and typically agency policy, that an inventory be conducted of sites that might be eligible for inclusion in the National Register and other lists of protected sites. Knowing the location of such sites permits avoidance during construction or other ground disturbing activities, which, in the case of the military, includes training activities. Inventories as they have been conducted often only locate sites, but do not determine conclusively that sites found are or are not eligible for listing on the National Register, or other, more local, registers. Therefore, if sites cannot be avoided, then they must be subjected to additional research, an evaluation to determine with confidence whether or not they are eligible to be listed on registers of protected sites. Evaluations can be quite expensive. In general, the more complex the site, the more expensive. Further, if the site is determined eligible and the agency for some reason cannot avoid disturbance to the site, it must be subjected to mitigation excavation. This is even more expensive than evaluation. Again, the more complex the site, the more expensive the excavation.

Therefore, what would be especially useful to land management agencies are survey techniques that allow identification of the more complex sites. These are the sites most likely to require expensive and time-consuming evaluation, and possibly mitigation excavation. We intend to develop protocols for the use of SAR technology deployed from aircraft with this in mind.

Objectives of This Research

Protocols will be directed especially to finding and characterizing archaeological sites located in arid and simi-arid environments typically found in the American West, where the Department of the Defense, and many other government agencies, have stewardship over large areas of land. Accomplishing these objectives will, therefore, require testing in an area containing a set of targets representing, as much as possible, the full range of archaeological features found in arid and semi-arid environments. Further, to maximize the transferability of the protocols devised by this research, these archaeological features will be located within a set of environmental zones that resemble as many as possible of the environmental zones found on DOD lands. San Clemente Island offers targets and environments similar to those found on many DoD lands in the West. Finally, the research will seek to identify, at least in a preliminary way, sites that are complex, and so that are most likely to require time-consuming evaluation and, in some cases, mitigation excavation if agency activities are not directed away from these sites.

Research Activities

Phase I will be the collection of AIRSAR data, which includes three radar wavelengths: C (5.7 cm), L (23 cm), and P (67 cm). Each band will be polarized so as to be transmitted and received horizontally or vertically, which will affect the way the radiation interacts with materials on, and, in some cases, below, the ground. This multi-polar data will differentially highlight objects of certain sizes, shapes, and spatial orientations. It will also affect the degree to which waves will penetrate soil and vegetation cover. The angle at which the radar waves are transmitted will also affect backscatter: objects that present a face to the radar waves will likely be well represented in backscatter data, while those presenting a thin edge are less likely to be detected. Therefore, the AIRSAR platform will conduct several data collection flights over San Clemente Island, some at perpendicular angles (Fig. 7).

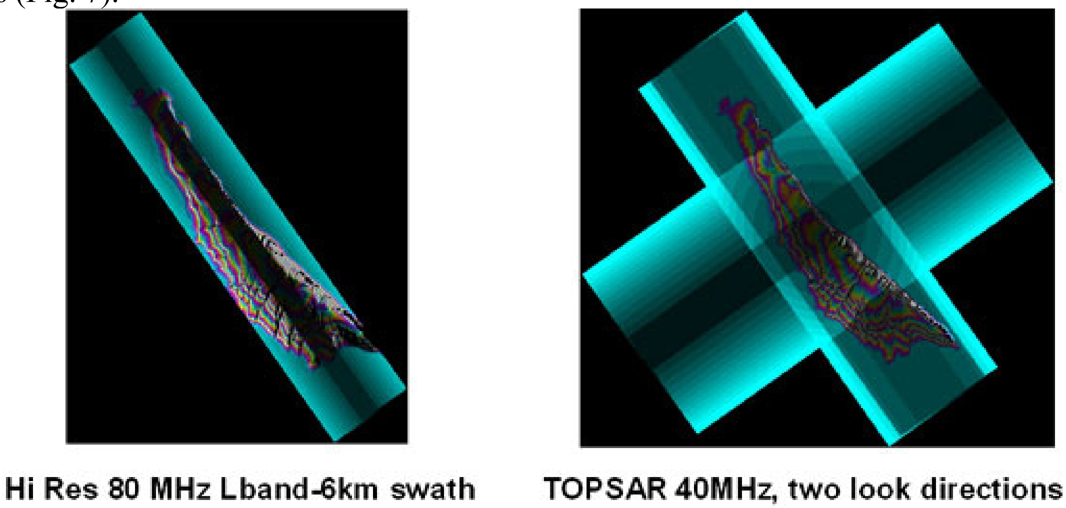
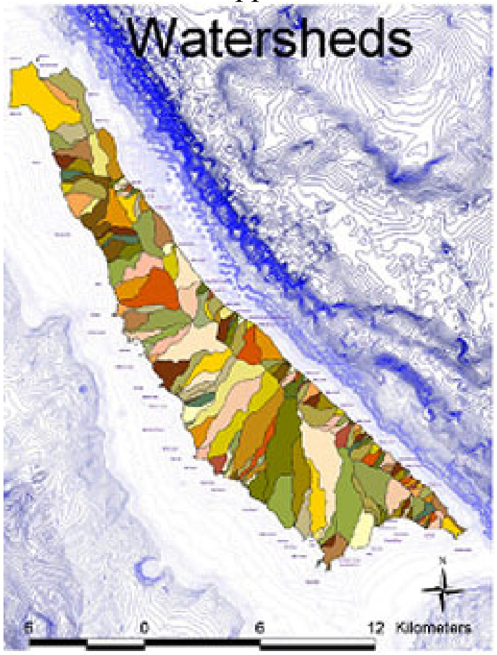


Figure 7 AIRSAR flight lines over San Clemente Island

In addition, we hope to acquire GeoSAR P and X band image and topography data for incorporation into the analysis. In addition to the X band wavelength provided by GeoSAR, this instrument provides opportunity to evaluate potentially commercially available systems for this type of work.

Data will then be processed and images produced for all wavelengths and polarizations. JPL/NASA will also orthorectify images, using a DEM produced by AIRSAR data collected in TOPSAR mode.

Concurrent with AIRSAR data collection, a review of the GIS that has been constructed for San Clemente Island will be conducted to ensure accuracy of the locations and characterizations of sites and features recorded there (Fig. 8). Reports and field notes will be examined to supplement the GIS with any of the following information that might



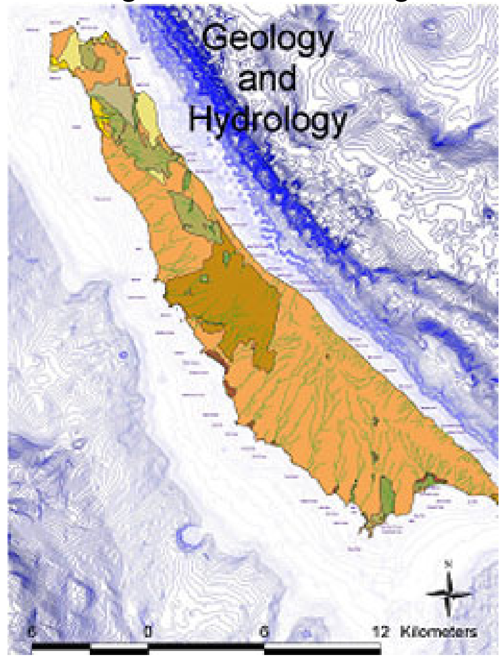


Figure 8 Two of the many themes in the San Clemente Island GIS

exist: size, shape, orientation, composition, environmental context, and precise location of sites and features.

The orthorectified radar images provided by JPL/NASA will be imported as themes into a GIS already established for San Clemente Island, which displays the location, identities, and other descriptive information for numerous archaeological sites and features. Fig. 9 displays the expected sorts of sites and features. Other themes pertinent to natural and cultural conditions on the island will also be brought into the GIS, as will images, and images produced by merging multispectral and hyper spectral images with radar images.

Site Types	Intra-site Features	
	Small (<2m)	**Large (>2m)**
Prehistoric carbonaceous middens	Hearths	House floors
Prehistoric artifact and shell scatter/deflated middens	Pits (e.g., storage, trash)	Pit houses
Paths	Ceremonial features	Ceremonial enclosures
Prehistoric lithic and ground-stone quarrying	Burials	
Isolated prehistoric structural features		
Historic sites		
Natural springs and seeps		
Natural cisterns		

Figure 9 Some expected types of sites and features on San Clemente Island (all have been recorded during previous fieldwork there)

The GIS will be used to produce a predictive model of the distribution of archaeological sites and features on the island. Various post-processing protocols will then be employed on radar images. Anomalies will be identified by means of this analysis, and through comparison with other themes in the San Clemente GIS. Among other post-processing protocols systematically tested will be those that can better highlight objects that might be underrepresented in data collected at certain angles of incidence by adjusting shaded relief. Also, the post-processing team will systematically test the ability of each band and polarization to detect sites and features for which precise locations and characteristics have been recorded. Following this, the team will systematically test combinations of bands and polarizations to produce full color images. In addition, the team will systematically test the ability of images that have been synthesized with multispectral images to detect the known sites and features. The post-processing team will then develop hypothetical signatures for the array of sites and features detected in images.

A ground truthing team will be lead by Dr. Brian F. Byrd, who conducted the inventory surveys on San Clemente Island during which most of the recorded sites there were discovered. This information will guide ground truthing fieldwork. Archaeologists will go to locations that correspond to anomalies seen in imagery and document key aspects of the features or sites found there. The following information will be recorded for each feature or site: size, shape, orientation, composition, environmental context, and precise location (using post-processing GPS equipment of total workstations). All features and sites observed will be photographed.

Dr. Douglas C. Comer will prepare a report, with input from other research team participants, that describes the protocols that were employed in Phase 1 for radar data collection, data processing, post-processing and image analysis, the designation of anomalies seen in imagery as signatures, the formulation of the predictive distribution model and its use in the designation of signatures, results of ground truthing, and recommended alteration of protocols to be used in Phase 2 of the research.

The protocols developed by this research are intended to make practical the use of synthetic aperture radar in finding and evaluation archaeological sites. Protocols will focus especially on finding sites that are most likely to be the most important and challenging from a cultural resource management point of view: structural sites, sites with middens, and sites that have been occupied over an extended period of time or reoccupied repeatedly with the result of altering soils chemistry and vegetative pattern. Processes by which specific radar bands and polarizations will be much better understood, and understood at least to the degree that they can be better applied to finding and characterizing archaeological sites. The protocols will in effect produce a pilot scale system for this application of synthetic radar technology to cultural resource management. If successful, the protocols developed will greatly reduced the cost per acre for inventorying archaeological sites in environments similar to those in the test area (San Clemente Island). It is indeed possible that protocols can be modified in the future for use in more heavily vegetated areas, where cost per acre for archaeological survey is substantially higher than in the generally arid environment of the West. Also, these protocols will in some cases produce a preliminary characterization of the sites discovered, which will result in a decreased expenditure in time and money to site evaluation efforts required prior to disturbance of known archaeological sites.