

ANGKOR: EXTENT, SETTLEMENT PATTERN AND ECOLOGY. PRELIMINARY RESULTS OF AN AIRSAR SURVEY IN SEPTEMBER 2000

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ABSTRACT

The airborne synthetic aperture radar (AIRSAR) survey completed by NASA's Jet Propulsion Laboratory (JPL) for the Greater Angkor Project in September 2000 shows that Angkor was the largest, low-density, dispersed urban complex of the pre-industrial world. The World Heritage site is both the location of the largest group of religious structures on the planet and the location of the most extensive urban complex prior to the late 19th-early 20th centuries AD. The entire complex is a single cultural entity that requires an integrated approach to its management, its conservation and its interpretation to the public.

THE GREATER ANGKOR PROJECT

The Greater Angkor Project studies the extent, duration and demise of Angkor, the great medieval capital of Cambodia between the 9th and the 15th centuries AD (Dayton 2001). The Project is an international research collaboration between Apsara, the Cambodian government agency that manages Angkor; the Ecole Française d'Extrême-Orient (EFEO), the French government institution that has studied Angkor for a century; and the University of Sydney's Department of Archaeology and Spatial Science Innovation Unit. As a result of collaboration with the World Monuments Fund and the Mekong River Commission, NASA/JPL obtained a 7000 km² AIRSAR radar coverage of the region around Angkor in September 2000. Courtesy of a sponsor in the USA who has provided his expertise as a pilot, the project also has an Australian-made ultralight plane for low altitude aerial survey work at Angkor. The work is providing a new map of the city to assist with the management of the Angkor World Heritage site, which now receives about 300-400,000

tourists each year and is envisaged as having around a million visitors each year in five years time. The results of the Greater Angkor Project are also of consequence for our understanding of the present and the future relationship between urbanism, land use and ecology in Cambodia. The nature of Angkor as a giant low-density, dispersed city covering at least 1000 km² (Figure 1), and the relationship between past and present environmental deterioration in Cambodia due to extensive land clearance, are highly topical issues for land use policy.

AIRSAR

Since the mid 1990s a new remote sensing tool, radar, has been brought in to help survey Angkor. An initial radar survey of Angkor from the Space Shuttle Endeavour, carried out in 1994 at the request of the World Monuments Fund, gave for the first time a single integrated image of the whole region around central Angkor. What is important is not that the addition of airborne radar might reveal new monuments. It does not. What it does is to offer an observer a holistic view in which scattered parts of a whole become understandable as one phenomenon. Most important, the radar clearly showed the great axial north-south canal extending from the hill ranges to just north of the north gate of Angkor Thom. In addition it was apparent that there are numerous linear features that lie approximately at right angles to the axial watercourse. This suggests that the urban complex might be far more extensive than had previously been envisaged. While the great northern linear feature is noted, in part, on some earlier maps, in part in the ZEMP Project (Engelhardt 1996), and is also partially recognisable on the standard maps and on the notable Japan International Co-operation Agency (JICA) GIS survey of 1999, as well as the Spot and Landsat images, it has not, prior to the new

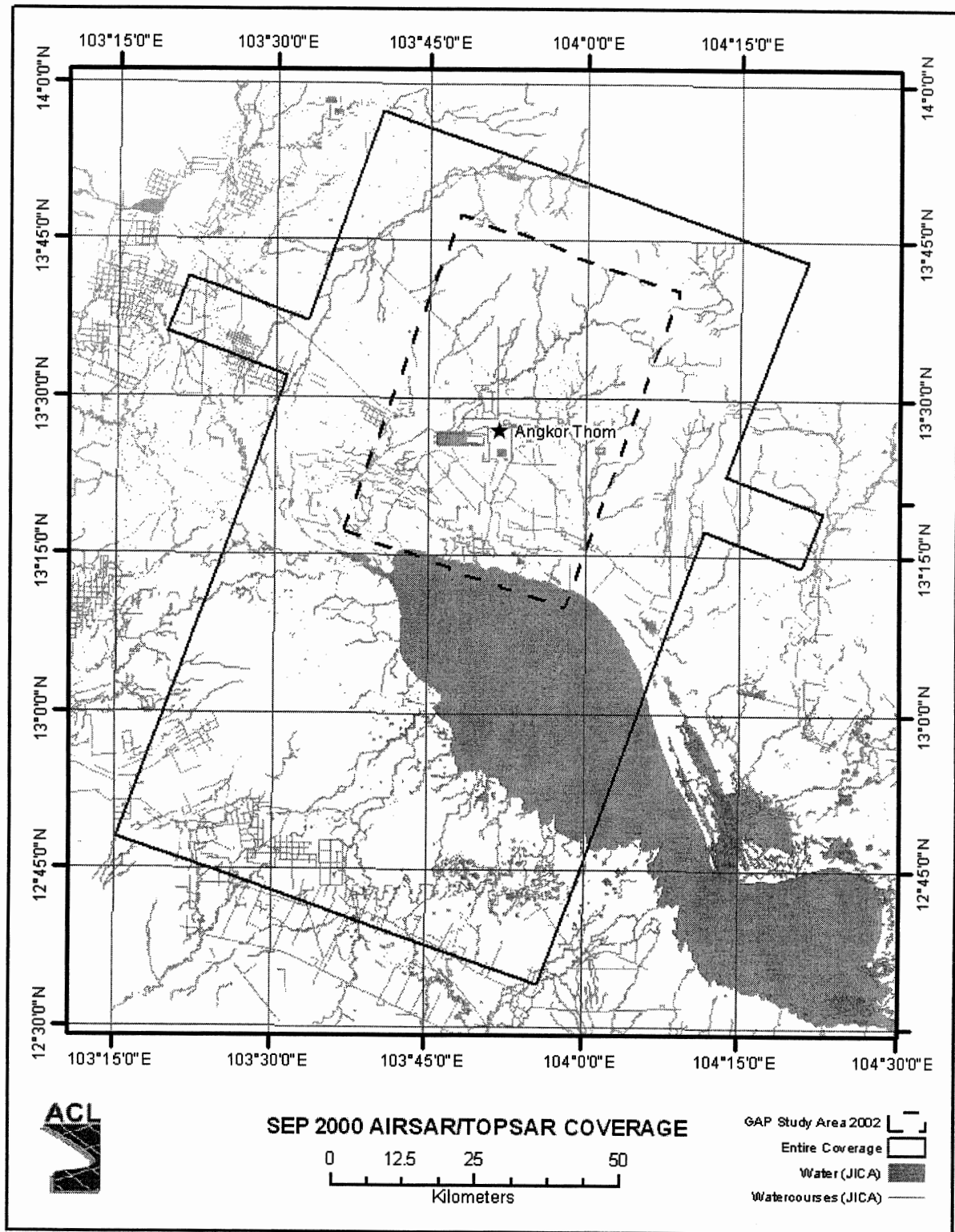


Figure 1: 7000 km² AIRSAR survey area covered by the September 2000 mission around Angkor in Cambodia - enclosing the 3000 km² survey which covers the urban complex.

AIRSAR survey, been discussed as a critical feature of the spatial layout of Angkor.

Following the 1994 space-borne radar survey, Dr Elizabeth Moore arranged for NASA/JPL to carry out selective sample transects across central and western Angkor using airborne radar (AIRSAR) in 1996. While her emphasis was on pre-Angkorean 'circular' village enclosures and on seeking undiscovered temples, the 1996 survey showed clearly that great detail could be acquired from aerial radar both in terms of detail, such as the fields which can be seen in the aerial photographs, and in terms of environmental phenomena such as partially concealed water flow and vegetation regimes. The critical value of the radar is that it uses three different frequencies, and collects the polarimetric signals from the radar return that rebounds from the ground. Because the different wavelengths of the radar interact differently with the surface texture and the groundwater of the landscape the system is immensely valuable for the analysis of landscapes and relationships between natural and cultural features. The AIRSAR data allow an integrated approach to the study of the Angkorean landscape, providing the opportunity and the means for the analysis of the diverse results provided by numerous differing combinations of radar frequencies and their associated suite of polarimetric return values. This capacity of the radar data allows a diverse suite of digital enhancement techniques to be applied as a way of seeking out spatial patterns. When combined with the AIRSAR-derived digital elevation model (DEM) that allows the creation of a 5 m interval topography of the region, a 3D virtual model of the landscape can be built as a tool for 'seeing Angkor'.

Our ability to 'see' Angkor today from the air generally depends upon the actual experience of generations of farmers who knew the lie of their land and exploited it, creating patterns of housing and fields that reveal the past. The multi-frequency image data from AIRSAR allow us to inter-relate present day crops and past heritage landscapes. Angkor was not just Angkor Thom, nor a collection of great temples concentrated around it, nor is its extent defined by the great reservoirs or *baray* (Fletcher 2001). Instead, it can now be seen as a vast, ephemeral construction of sand and timber – a low density dispersed urban complex spread over more than 1000 km² from the Tonle Sap to the sandstone outcrops at the north of the Angkor plain.

THE SEPTEMBER 2000 AIRSAR SURVEY MISSION OVER ANGKOR

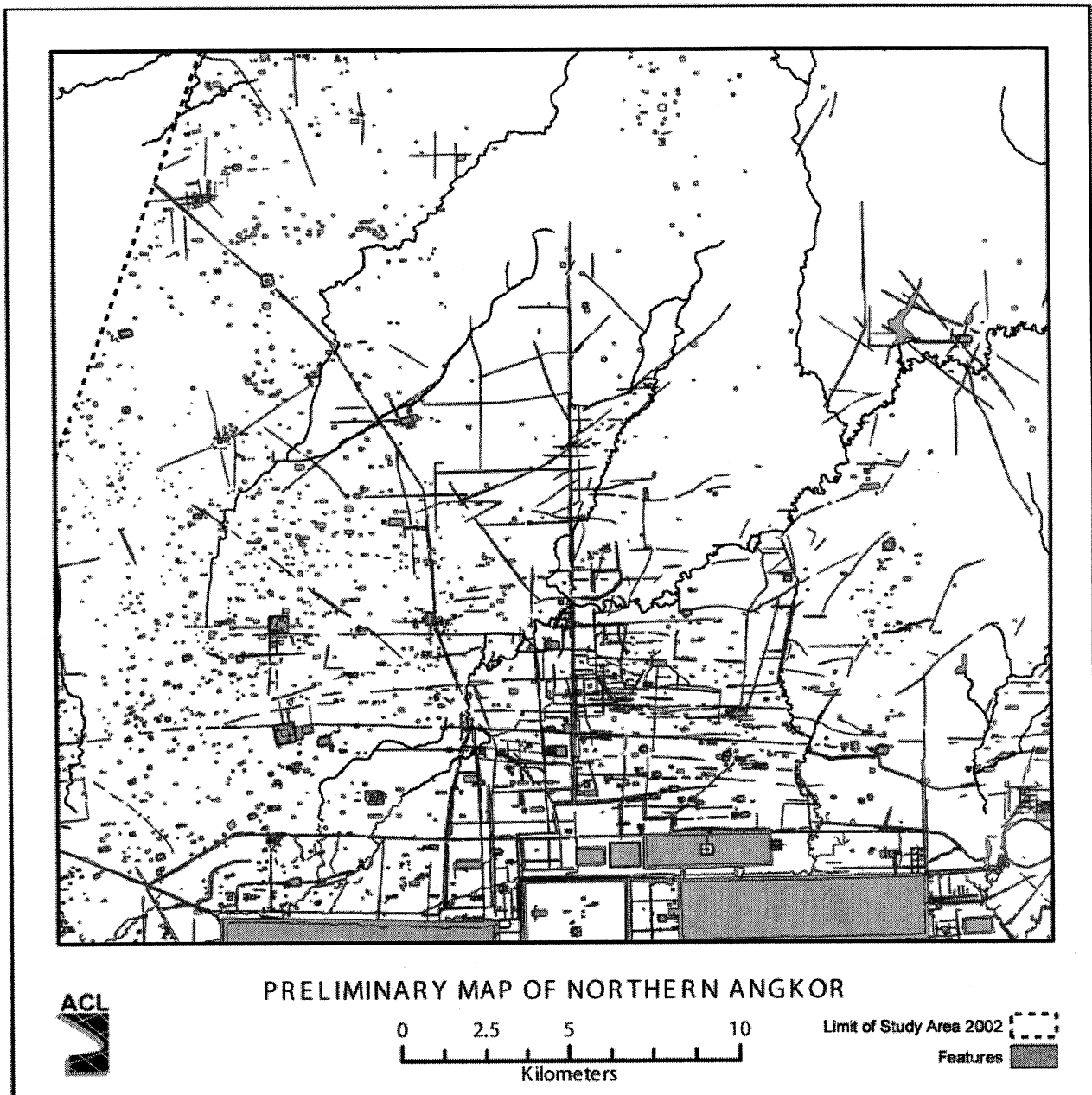
Acquisition of the AIRSAR data occurred through 98% cloud cover under stable flying conditions covering 7000 sq km² over the western end of the Tonle Sap including the Angkor area, the southern shore of the lake and an area stretching westwards towards Battambang. The focus of the Greater

Angkor Project is the 3000 sq km centred on Angkor. This area extended from the lake to the northern edge of the Kulen and Khror hills and from Beng Melea in the east to the Sung Srok west of Angkor. Landmarks such as canals, road embankments, 'house-mounds', water tanks, fields, temples and other structural features are being identified in three-band colour composite images and the information collated in preparation for assessment in a GIS environment. The excellent spatial quality, clarity and integrity of the data have enabled detailed mapping down to the magnitude of features such as field banks, approximately 60-80 cm wide. This is greatly assisting the mapping of Angkorian period features, especially in areas where the ground is inaccessible due to uncertainty about anti-personnel mines. In addition, the images show that modern rice fields and an older field system are being picked up in the same locality and that, therefore, temporal palimpsests of features are visible in the radar data.

The initial analysis of the data has led to the following conclusions:

Spatial layout: Pottier's work (1999, 2000) has shown that a dispersed pattern of occupation is present in the south and a GIS based analysis of that data has shown that there is a consistent relationship between residential mounds, local shrines and water tanks (*trapeang*). The September 2000 AIRSAR complements this work by allowing a rapid identification of the equivalent scatter of shrines and *trapeang* in the northern half of Angkor (Figure 2). The distribution of the house mounds and *trapeang* is not the same as distribution of the linear features such as embankments and channels, suggesting that there is a decoupling of the residence pattern from the macro-scale infrastructure. In addition, the distribution of residence in a dispersed form extends all along the north side of the Tonle Sap and off to the north-northwest. Therefore, the extent of the city must be defined in terms of the interconnected embankments and canals which formed an extensive communication network of roads and waterways. This is of some significance since the excavations and surveys of the Greater Angkor Project have shown that people were also living along the banks of the canals and along road embankments – as they do along modern roads and canals in the region.

Water management system: Pottier has identified inlets and outlets for the *baray* in central Angkor, and huge canals extending southwest and southeast from them. One aspect of the old 'hydraulic city' debate, about whether Angkor had a hydraulic network capable of large-scale irrigation (Groslier 1979; van Lier 1980; Acker 1991), should therefore be at an end. What is now required is a comprehensive study of the water management system because understanding the duration and demise of Angkor depends on



*Figure 2: Preliminary map of archaeological features in the northern half of Angkor.
(Mapping of the baray and immediate area by Pottier 1999, otherwise by Damian Evans)*

this information. Evidence derived from enhancement of the AIRSAR data indicates the presence of an extensive hydrological network. Linear features detected in the AIRSAR data have been identified as Angkorean canals and feeder channels, many of which cannot be detected in other datasets, or which have no surface evidence. For example, the main southeast canal extending from the West Baray to the Damdek canal has almost no surface expression, yet it can be mapped in its entirety from the radar imagery due probably to a subtle difference in soil moisture and its impact on the local vegetation. The former canal is possibly a collector and conduit for subterranean water flows that impact on the local vegetation.

The survey provided by the September 2000 AIRSAR mission enabled the rapid recognition of the vast network of channels in the north. This network is complementary to and different from the channel system in the south of Angkor. The northern network can be seen as a controller and collector of water while the southern half is a dispersal and a delivery system. The West and East Baray and the Jayatataka (the northern *baray*) are the junction of the two systems. An additional feature deserving of more study is that the local shrines in the north seem to have more to do with the linear features than they do in the south.

Economy and ecology: The AIRSAR-derived digital elevation model is an essential dataset for understanding the dynamics of the fluvial environment of the Angkor region. Due to the timing of the data acquisition at the height of the wet season, channels and other features which hold water can be recognised even in the dry northern part of Angkor. When filled with water such features become readily visible on the radar images. Traces of discontinuous channels are evident. Roughly circular features that occur intermittently along these former channels in the northeast of Angkor are possibly meanders in a now-extinct fluvial system that have been transformed into circular features and maintained through agricultural use. Colour composite images derived from the AIRSAR data provides an excellent image of the channels and emphasise the meandering nature of the former system, while the precision elevation data indicates that some surface flow occurs between the circular features even today. Moreover, in at least two locations in the area to the north of the East Baray, the radar data shows that the circular features have been adapted into a typically rectilinear Angkorean form, providing some insight into the relative date of the fluvial system in this area.

A particular emphasis of the AIRSAR survey is on the northern, poorly known, half of the city up to and including the pediment slopes of the Kulen hills. Together with details on the extent of land clearing and the development of agriculture in the potentially unstable foothill slopes, the DEM data are being modeled to examine the potential impact

of these practices on the health of the regional ecosystem. A key focus of the Greater Angkor Project is the relationship between the vast extent of Angkor in the 12th to 15/16th centuries AD, land clearance for rice production, and regional ecological damage both then and now. There may have been risks associated with a low-density city that over-extended rice agriculture and excessively cleared forested land, especially once that clearance got into the lower slopes of Kulen where increased erosion would have resulted (Bruijnzwel 1990). In the 1980s and 90s, forest clearance was associated with severe flooding and erosion (Ung Phyrun 1990; Devine and Van Rouen 2001). The study has implications for the past and the future health of the ecosystem, sustainable development and the management of Angkor as a national and international cultural resource.

CONCLUSIONS

An analysis of 3000 km² of the AIRSAR radar survey in September 2000 around Angkor in Cambodia has revealed that the urban complex covered more than 1000 km², with most of the major temples located within the central 200 km². The radar survey completed by NASA/JPL for the Greater Angkor Project has now shown that a network of embankments and canals extends for at least 15-20 km out from the centre. This network is surrounded by, but does not have a consistent spatial correlation with, the dispersed distribution of residential mounds and local shrines that was first identified by Christophe Pottier of EFEO in the southern half of Angkor in the mid 1990s. The radar has also revealed local shrines and occupation sites on the lower slopes of the Kulen hills, far away from the centre of Angkor.

The radar shows that Angkor was the largest, low-density, dispersed pre-industrial urban complex. This has substantial implications for the significance of Angkor since it makes the World Heritage site both the location of the largest group of religious structures on the planet and also the location of the most extensive urban complex of the pre-industrial world. The entire complex is a single interconnected cultural entity that requires an integrated approach to its management, its conservation and its interpretation to the public.

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