AIRSAR'S CONTRIBUTION TO UNDERSTANDING THE ANGKOR WORLD HERITAGE SITE, CAMBODIA – OBJECTIVES AND PRELIMINARY FINDINGS FROM AN EXAMINATION OF PACRIM2 DATASETS

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In September 2000 AIRSAR-TOPSAR data were acquired over the environment and cultural landscape of the World Heritage site of Angkor in Cambodia as part of a collaborative research project between APSARA (Royal Cambodian Government Agency responsible for Angkor), EFEO (Ecole Francaise d'Eextreme Orient) and the University of Sydney. Termed the Greater Angkor Project, additional support from the World Monuments Fund and the Mekong River Commission funded the acquisition of 3000 sq km of data as part of a total of 7000 sq km coverage of the western end of Lake Tonle Sap. These data provide the first comprehensive, consistent and detailed record of the whole of Angkor and its surrounding region. An enhancement in Figure 1 shows the
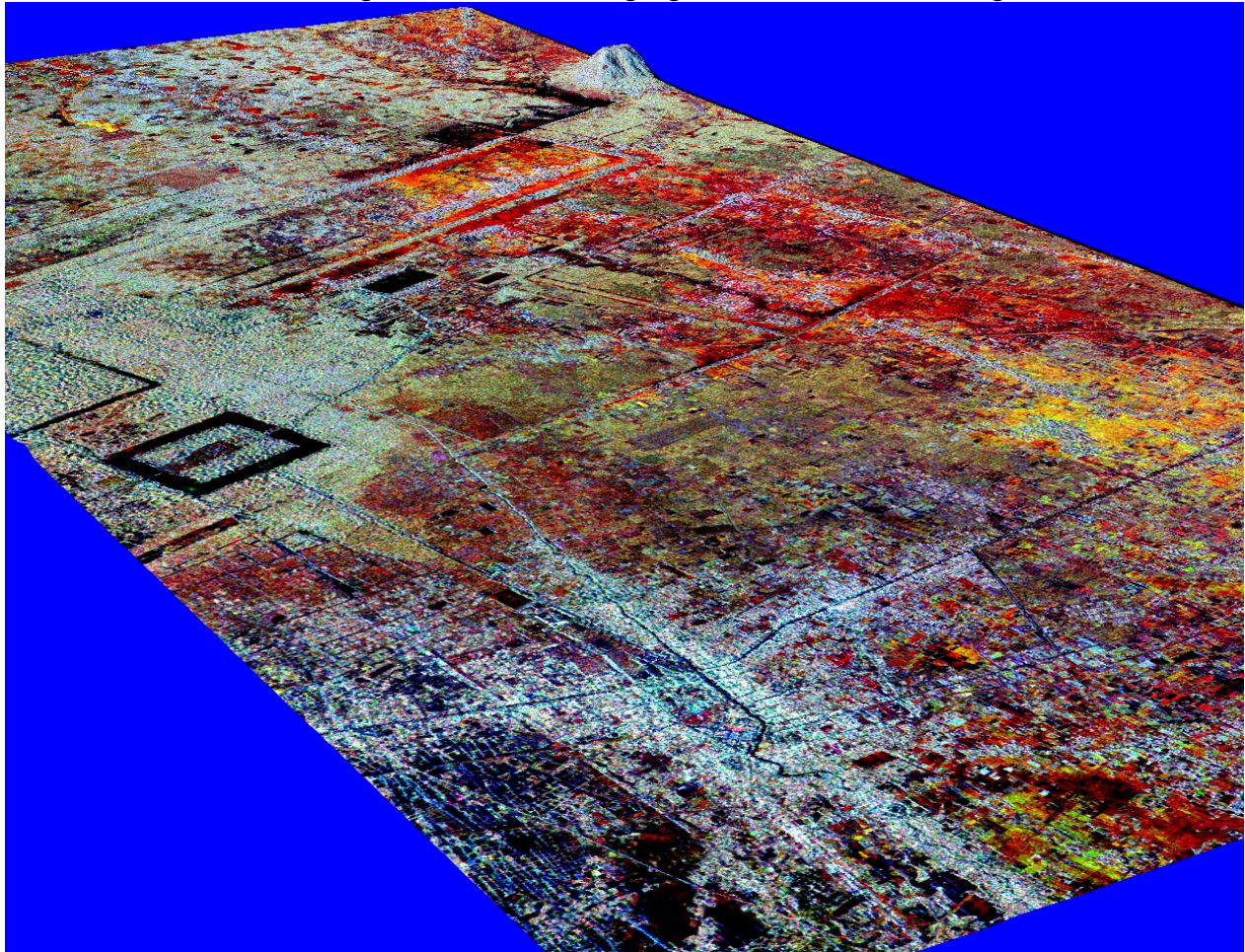

Figure 1: AIRSAR bands Cvv/Lvv/Pvv displayed as RGB, respectively, draped over TOPSAR DEM with a 7x height exaggeration – a northeasterly perspective view across the town of Siem Reap, in the foreground, to the ricefields south of Angkor Wat (left center) and former reservoir of the East Barray, to the outcropping rhyolite hill of Phnom Bok and beyond to alignments of sinkhole ponds developed over a karst? plain in remnant alignments of a former drainage network comprising the Roulus and Siem Reap rivers. The data have a spatial resolution of 5x5 m and dimensions of 30x10 km.

location of the capital of the former Khmer empire of Angkor from the 9th to 16th centuries, centred on the archaeological temples of Angkor Wat and Angkor Thom. In the foreground is the urban sprawl of the present-day provincial town of Siem Reap, the largest town in the Tonle Sap Basin. It is expected that enhancements of PacRim2 radar datasets will be the key to providing archaeologists and researchers with vital information for: 1) developing a comprehensive map of the entire urban complex of the former Khmer empire, which on current estimates covers more than 1000 sq. km; 2) determining its duration; and 3) identifying reasons for its demise. These are the three specific objectives of the Greater Angkor Project. The foremost objective, mapping, will assist in identifying sampling procedures for the other topics of the Project.

Acquisition of the AIRSAR data occurred through 98% cloud cover under stable flying conditions. The amplitude or radar brightness Cvv and L and P polarimetric data accompanying the TOPSAR DEM have been masked of pixels with out-of-range finite values, non-numbers and infinite values, normalized to correct for variation in antenna pattern intensity, and "cleansed" of noise and speckle. Geometric correction was affected by firstly rotating the data to the direction in which the flightline was flown and then fitted to a local map projection coordinate system using the corner map coordinates supplied in the data header file. The TOPSAR DEM file was similarly processed.

Landmarks such as canals, road embankments, "housemounds", 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 the features the size of banded 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 uncertainties about anti-personnel mines. In addition, the images show that the modern rice field systems and the old Angkorian period fields are being picked up in the same locality and that, therefore, temporal palimpsests of features are visible in the radar data (Figure 2).
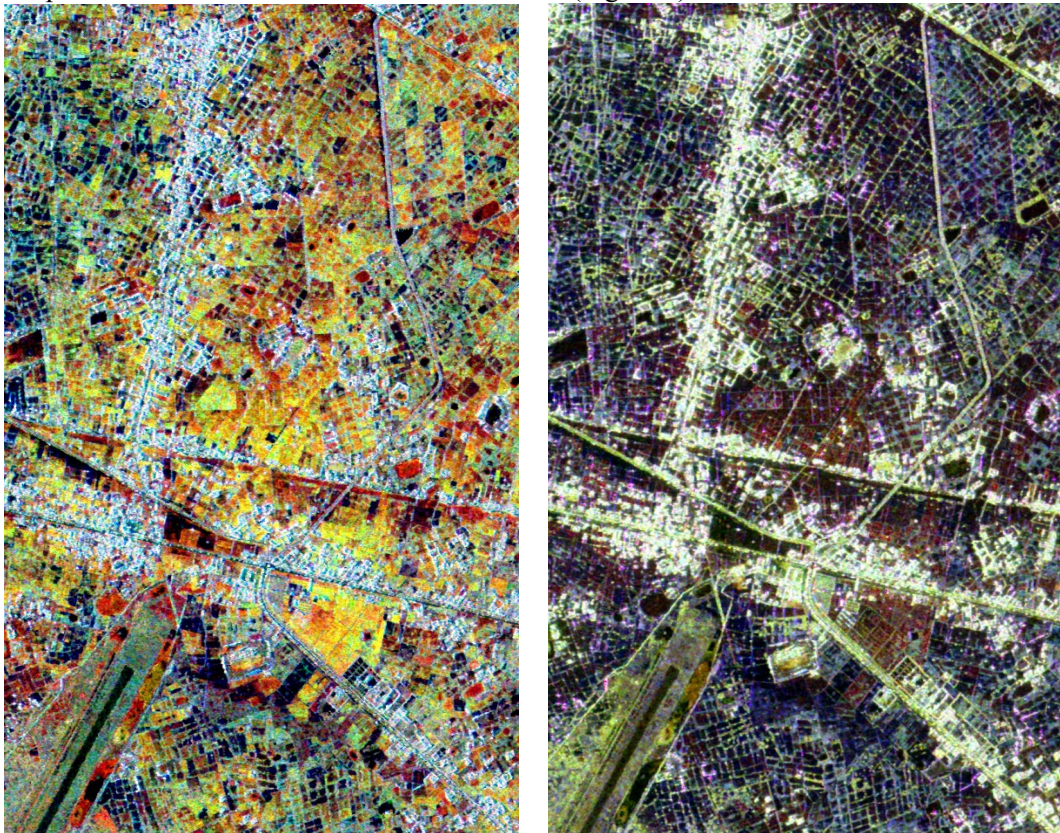

Figure 2: A comparison of two enhancements of AIRSAR data of an area approximately 3x2 km immediately south of Siem Reap airport. The left image, Cvv/Lvv/Pvv provides a high level of separation between rice crops based on colour and texture, whilst the right image, Lhh/Lhv/Pvv, maps the various alignments (ages) of rice fields. The ability to extract this information will greatly facilitate environmental and hence ecological analysis.

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 where 3D perspectives provide excellent and informative images of the landscape (Figure 3). 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 by these practices on the health of the regional ecosystem. A key issue of the Project is the relationship between the vast extent of Angkor in the 12th to 16th centuries AD, land clearance for rice production and regional ecological damage both then and now. 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.
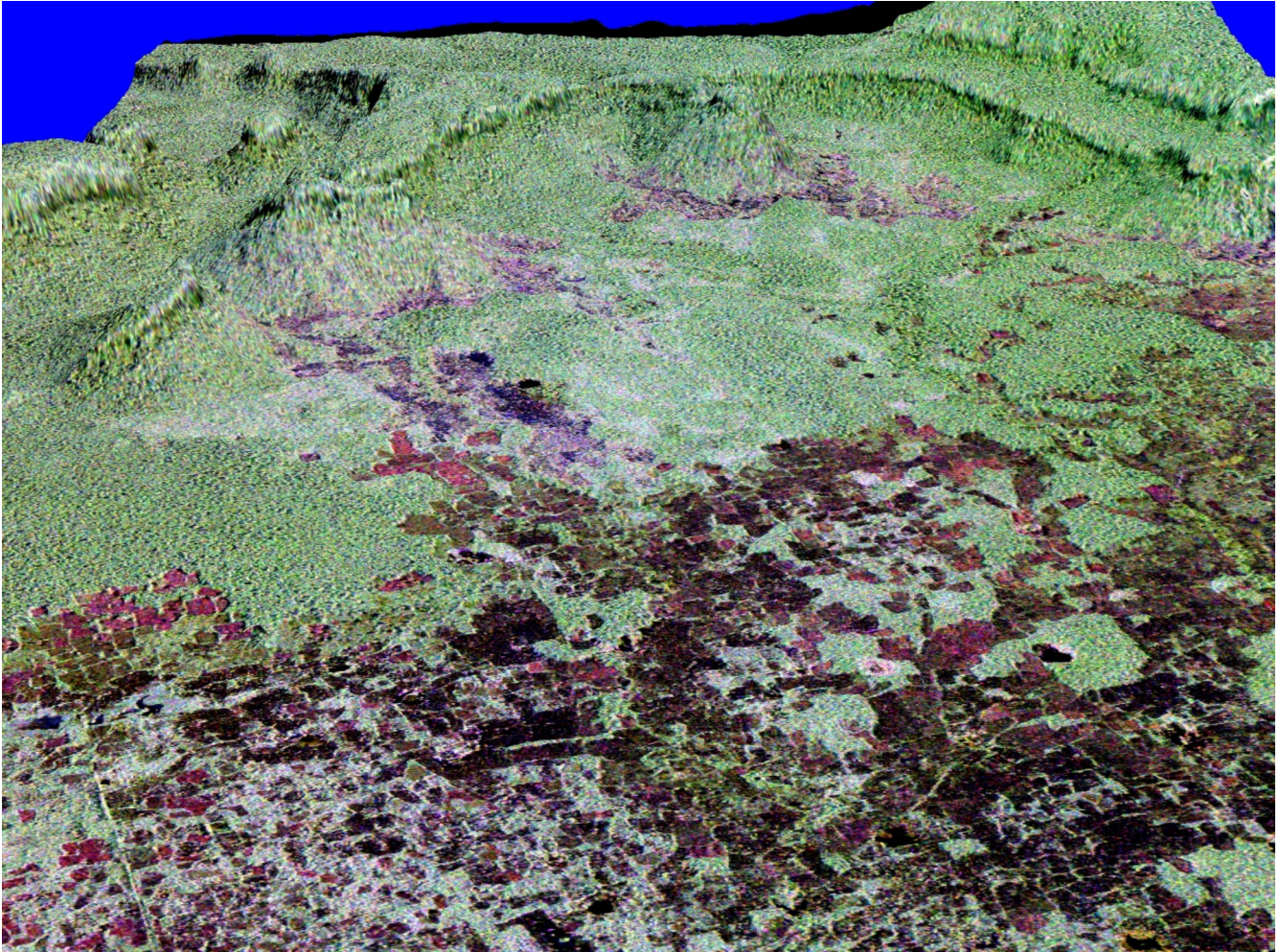

Figure 3: 3D perspective model of AIRSAR bands Lhh/Lhv/Pvv displayed as RGB, respectively, and overlaid on the TOPSAR DEM. The stripping of native forests for rice production by the practice of slash and burn is very evident. Of concern is the rapid encroachment of land clearing onto the potentially unstable footslopes of the Kulen hills and the possibility of accelerated erosion causing siltation and the blocking of water management systems, a situation that may have occurred in the latter stages of the Angkorian period contributing to its demise. It is possible that the Khmer created an ecological disaster that may be about to repeat itself by impacting on the Lake Tonle Sap environment.

Apparent terracing in the foothill slopes that can be traced beneath the forest canopy in enhancements of the longer wavelength data may represent the position of Angkorian rice fields. These and other faint traces of recta-linear features that may provide evidence on the position of former hydrological systems and human occupation are being investigated during field trips to the region by the Project team.

The study of the duration and demise of Angkor requires an understanding of the water management system. Evidence in enhancements of the AIRSAR data indicates that the Angkorian field system was associated with an

extensive hydrological network. Linear features detected in the AIRSAR data have been identified as Angkorian canals and feeder channels, many of which cannot be detected in other datasets or have any surface evidence. For example, the main southeast canal extending from east of Angkor Wat to Lake Tonle Sap has no surface expression yet 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 TOPSAR DEM is an essential dataset for understanding the dynamics of the fluvial environment of the Angkor region. It was fortuitous that the AIRSAR data were acquired at the height of the wet season when otherwise dry channels and shallow flowlines in the northern sector of the survey area would have been dry. Tracts of discontinuous channels are most evident in the data as can be seen in the Lhh/Lhv/Pvv image in Figure 4. Circular-like features that occur intermittently along these former channels are probable sinkhole ponds that tap the shallow water table in a karst environment. Today water buffaloes frequent these ponds thereby helping to maintaining their circular shape. The 2D relief model in Figure 4 provides an excellent compilation of the channels and highlights the meandering nature of the former system. Because the karst substrate is so highly permeable and infiltration rates high, surface flow does not occur, even during the wet season. Rather, subterranean flow along these channels leads to increased soil saturation and their detection in the radar imagery.
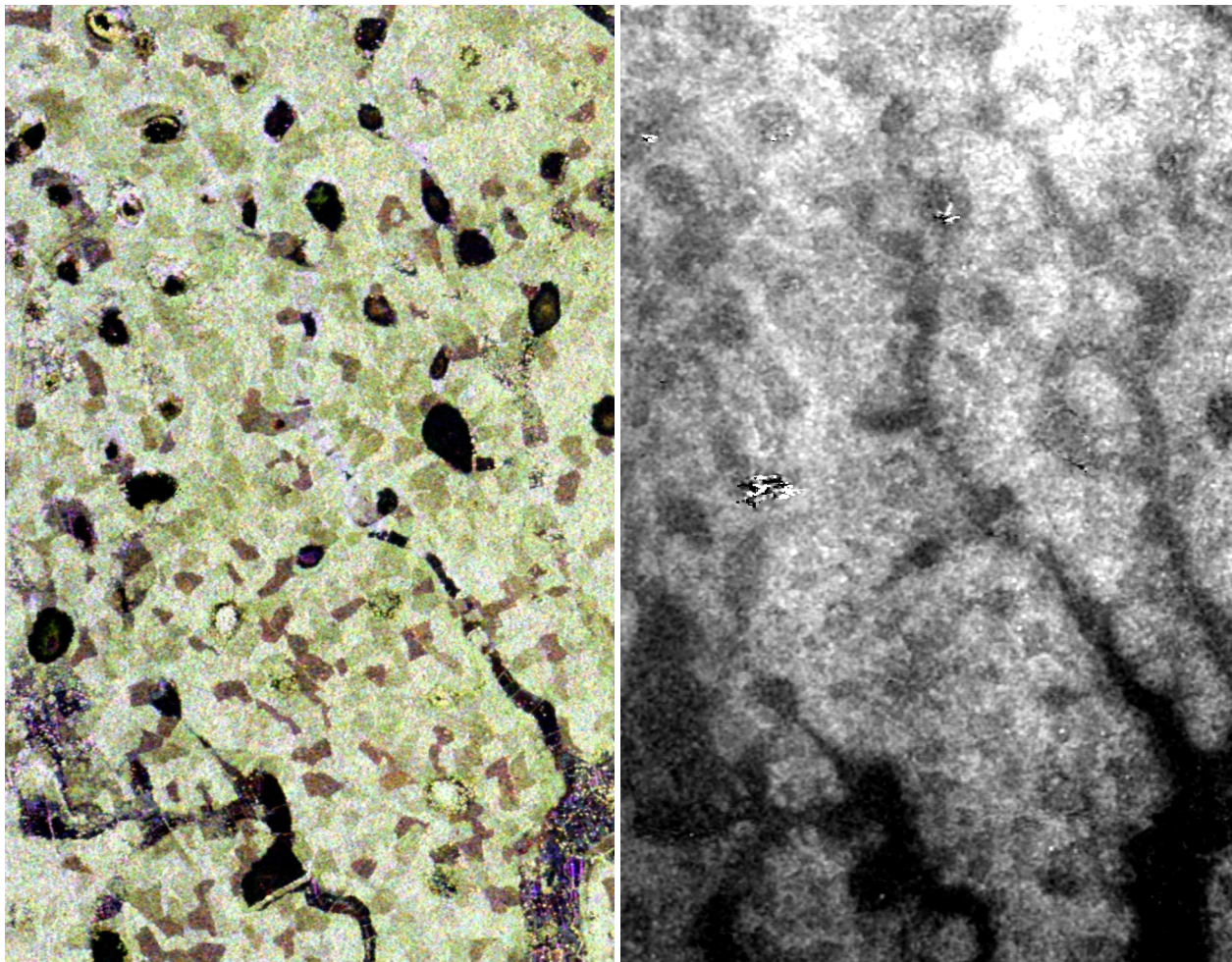

Figure 4: A colour composite image of AIRSAR bands Lhh/Lhv/Pvv (left) and a 2D relief model generate from the TOPSAR DEM demonstrate the capability of these data to reconstruct the alignments of former drainage networks

In conclusion, there can be no doubt that high resolution multi-parameter AIRSAR data are critical to the development of the study and are an essential tool for mapping archaeological sites in tropical environments.