

Angkor GIS, RS & Radar – Pioneering Contribution of Hungary to “Archaeology from Space”

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Abstract

The paper is not an account of events, research developments or results regarding issues related to the title. Rather, it is about my thoughts regarding the potential consequences of being involved with research developments related to the creation of a Geographical Information System (GIS) at Angkor (Cambodia), incorporating remote sensing data, such as aerial photography, satellite and radar images. Therefore, the article is not a classical “case study” on the application of these technologies at Angkor, since others have made a much more authoritative description or contribution on this issue. The paper is a story of a Hungarian who happened to be involved from the very first attempts of the application of GIS technologies at Angkor in 1990.

1. Introduction: several *nos* and a couple of *yeses*

The paper is not an account of events, research developments or results regarding issues related to the title. Rather, it is about my thoughts regarding the potential consequences of being involved with research developments related to the creation of a Geographical Information System (GIS) at Angkor (Cambodia), incorporating remote sensing data, such as aerial photography, satellite and radar images. In agreement with Mihály Polányi, knowledge is public and also to a very great extent personal (i.e. it is constructed by humans and therefore contains emotions, “passion”).¹ I am passionate about Angkor, and everything related to remote sensing and the archaeology of Angkor. Therefore, the article is not a classical “case study” on the application of these technologies at Angkor, since others have made a much more authoritative description or contribution on this issue. The paper is just a story of a Hungarian who happened to be involved from the very first attempts of the application of GIS technologies at Angkor in 1990. Hence the relaxed and passionate style of writing.

2. The vertical dimension

I will call the “vertical dimension” those research developments that are coming from an ever-increasing number of different research technologies applied at one particular archaeological site. In this case it means that several different non-intrusive methods, like remote sensing (aerial photography, satellite and radar imagery), geographical information systems, photogrammetry, to mention just a few, are applied to the same archaeological site.

2.1. ZEMP & the GIS

The Zoning and Environmental Management Plan of Angkor (ZEMP) was particularly successful, creative and unique during the United Nations Educational, Scientific and Cultural Organization (UNESCO) project in Angkor, between 1992 and 1995. The goal was to draw a baseline, i.e. collect all available knowledge for establishing a framework for future research and development in the historic area of Angkor, when the civil war had just ended and a new, peaceful era was beginning. The ZEMP made extensive use of GIS. The role of GIS was to “consolidate” and express different kinds of “research knowledge” in a digital map and the related database.

¹ I used here the summary of Polányi’s theory by Sveiby, Karl E. as it appears on the website <http://www.sveiby.com/articles/Polanyi.html> (31 December 1997).

2.1.1. Csáki's "GIS" for RAF (AGIS-1)

A GIS for Angkor was the idea of the author in 1990. I was impressed by the report of a Hungarian civil engineering delegation to Angkor in the late 60s. I convinced György Raskó, then State Secretary of the Ministry of Agriculture, with considerable international experience, to support a Hungarian expedition to Angkor. During the preparatory sessions of the mission it quickly became clear that only hydrology and land survey opened up opportunities for Hungary in a remote, and for us an unknown Southeast Asian country. The database was implemented by György Csáki and his wife, Annamária Csáki. The first version was further developed by four Hungarian geological and hydrological companies (BGTV, PGTV, FÖMI and VIZITERV) and financed by the Ministry of Agriculture. Data was collected during two missions of Hungarian surveyors and hydrologists in 1991 and 1992.

The first ever Angkor GIS (AGIS-1) contained mainly the following types of data:

- 3D image of a Bayon tower-head above the main Eastern entrance gate;
- a digital, vector drawing of a wall section of the bas-relief from the Southern side, Western section (the so called "Historical panel") from Angkor Wat;
- a 1 to 50.000 scale base map with the main central features of the historical area of Angkor, as identified from the aerial photographs from the William Hunt Collection of the School of Oriental and African Studies, University College, London; a 1 to 50.000 map prepared by Long Visalo in 1973 in Budapest; and a 1 to 500.000 map prepared by the US Army and the Republic of Vietnam in 1971.

The data is still in an envelope that was sealed when György Csáki finished his work on it. (I wonder whether we could still download it into a modern computer if opened.) Today, I would not call AGIS-1 a "real" GIS, since it did not relate different types of data to each other, nor did it make it possible to draw conclusions based on the relationship of that data to geographical location. However, it was a serious effort for a comprehensive approach towards the consolidation or "synergy" of very different research aspects and attitudes, previously considered irrelevant or useless for archaeology.

2.1.2. Hydrological survey of Garami & Kertai in 1992 & 1993

Parallel to the geological survey of the Angkor area and the photogrammetry of some towers in Preah Ko (in the capital of Angkor, called Hariharalaya in the 9th century, or Roluos today), two Hungarian hydrologists, Ferenc Garami and István Kertai prepared the first ever comprehensive hydrological survey and analysis of the engineering constructions of the historical site of Angkor. Certainly, topology was much better surveyed and mapped by French companies in the 1970s, as requested by the famous EFEO, in charge of safeguarding the monuments from 1896 until 1972. However, Garami and Kertai, in their pioneering study, for the first time ever, tried to interpret the development of the Angkor hydrological system from a purely hydrological engineering point of view. Their conclusions were incorporated into 8 charts or drawings that were a truly first time effort to show the sequence, scale and complex nature of the irrigational and hydrological interventions that were checked on the ground by engineers.

In short, art historians, philologists and historians were exposed, in a comprehensive and consolidated form, to the sobering realities of Angkor; while engineers were faced with the design and maintenance of a complex hydrological system. The conclusions of Garami and Kertai voiced strong reservations that were radical at the time, regarding the use of the large water tanks or *barays* exclusively, or at all, for irrigation purposes. This has become the prevailing opinion of the research community, independent of the fact whether the conclusions of the Hungarians were referred to or known at all. (It was submitted to the ZEMP and remained shelved at the UNESCO Information Center in the Angkor Conservation Office in Siem Reap, together with other scientific reports that were made by the participants of the ZEMP project in 1992 and 1993.)

2.1.3. Heng Tung's pigeons (AGIS-2)

UNESCO paid for the Hungarian experts involved in the development of AGIS-1 to incorporate it into the ZEMP project. ZEMP involved around two dozen experts to collect all the necessary information and evaluate them with the help of the "enlarged" AGIS-2 (as I refer to it). AGIS-2 incorporated all the available administrative, research and image data. The most important types of data that were actually used, not just simply incorporated, were the following:

- a base map of 1 to 50.000 scale, about 5 times larger than in AGIS-1 (around 2000 km²);
- detailed hydrological, geomorphological and environmental (including flora, but not fauna) map of the core area between Kulen Mountain and Tonle Sap (the Big Lake);
- detailed administrative map of Siem Reap province, including all roads, bridges, villages, communes, towns, population, transportation, fuel, market, industry data, etc.;
- archaeological data and an inventory of monuments, based on a completely novel identification of non-monumental sites of archaeological value.

The real breakthrough, however, regarding AGIS-2, and perhaps for the author as well, came from Heng Tung, an American GIS expert. He explained that the numerous layers in the AGIS-2 could bring “real” GIS results only if the two methods were applied or introduced during the build-up and use of the database. He asked experts to give a value to their objects, and the project manager was asked to give combined or consolidated values to them for the ZEMP project’s special zoning purposes.

He used an excellent example from his war experience, when pigeons were taught to recognize camouflaged tanks from aerial photos. First, rice seeds were placed over the military equipments on photos already recognized by human eyes, then, after several attempts, pigeons were pointing at places where they, but not humans, saw a similar pattern. Both new tasks opened new perspectives for AGIS, while the generated results were hardly used, or only to a minimum degree, during the ZEMP project. I can summarize the new approach as “tacit dimensions of knowledge”, using the term of Polányi.²

2.1.4. Moated sites of Dr. Moore in the ZEMP GIS

Another important breakthrough during the ZEMP came from Dr Elizabeth Moore. She identified more than a hundred potential moated sites at the Angkor plain that were settlements established well before the creation of the classical period of Angkor. By identifying and shortly describing them, Dr Moore was the first to visualize, and thus point at the much larger context of the Angkor civilization. The problem of transition from the Stone or Bronze Age to the Iron Age gave a radically new perspective to the research of the Angkor civilization. Dr Moore, by visualizing the intensive presence of a Neolithic civilization on the Angkor plain as a vital precursor to Angkor, changed the whole perspective or, in her own words, the “mindscape” of the research on the Angkor civilization.

Dr Moore’s new approach immediately generated new research questions that could not, or could have been answered only with great difficulties with the application of old archaeological methods. The suspected spread of the Neolithic communities along the fan shaped terraces and the intervention of these communities into the hydrological environment requested a “bird’s eye perspective” rather than an exclusively classical “digging” approach. A thorough and highly creative application of animistic local traditions added another strong flavour to her research.

During the next decade, Dr Moore made a pioneering research based on the SIR-C/X-SAR Spaceborne platform, then a later one, following the 1998 mission of the PACRIM/AIRSAR airborne platform radar data.

2.1.5. Kuszinger’s AGIS-3

When ZEMP was over in 1995, the database was consolidated by GIS experts Paul Box and later by Robert Kuszinger. The GIS developed by Kuszinger in the CSLM Department of Geoinformatics, Székesfehérvár (Hungary), made a major improvement on AGIS by incorporating a completely new set of data coming from the NASA/JPL Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR). Apart from the tedious work of “closing the polygons”, a whole new magnitude or new dimension of up-to-date GIS software environment or platform completely changed the size (8000 km²) and quality of the data available in the AGIS-3. To demonstrate this change, it is adequate to describe in a very short and concise form the main clusters of the 96 data layers in AGIS-3:

² “Hol kezdődik a tudomány? Meghallgatta mások gondolatait erről a kérdésről, de neki is megvolt a jól megalapozott válasza: »Ahol a jelenségek egy halmaza koherenciát és szabályosságot mutat.» (Source: The Recollections of Eugene P. Wigner as told to Andrew Szanton, Plenum Press, New York and London, 1992. p. 335.)

- digital Terrain Model T (10m between the closest points);
- lattice or Grid can be generated up to 10m/pixel resolution for the whole area (80 by 100 km) derived from topographical map contour lines by 10m (supplementary 5m);
- height information is given for contour lines in database;
- land cover in 26 categories (most of them for vegetation polygons that cover the whole area)
- data for botanical and wildlife values can also be related;
- infrastructure line data (10 categories of roads and other);
- hydrology (11 categories for hydrological feature);
- database linked for certain points to photographs, cross-sections, profiles, textual descriptions;
- zoning (plan) for Angkor Park (zone boundaries);
- soil types (polygons for 5 main categories);
- administration database for villages (number of buildings, population data, information for transport, fuel, etc.), commune and district boundaries;
- geology (4 base categories);
- monuments and archaeology database (linked to point locations with data for monuments (century, status, etc.), tabular, textual and image data;
- remote sensing (RADAR, SPOT, Williams Hunt Collection).

AGIS-3 was sold to the newly emerging team of Dr Roland Fletcher, Associate Professor at the University of Sydney. The seed from September 2000 for a completely new scale of research has fallen on a very fertile ground.

During my visit to the Jet Propulsion Laboratory (JPL, Pasadena), on 15 July 1995, a Memorandum of Understanding was signed by Dr Diane L. Evans, Imaging Program Scientist, JPL (currently Chief Scientist, NASA/JPL/Earth Science Office), Dr Tony Freeman, Head of the JPL Outreach Program, and myself, as Chairman of the Board of Trustees of the Royal Angkor Foundation, about potential future applications of radar imagery for archaeological and cultural resource management purposes. Application for the world heritage list was also contemplated already in 1995. Ten years later, on March 2 2005, NASA signed a Memorandum of Agreement (MOA) with UNESCO. “The purpose of the MOA is to foster improved global conservation through increased use of NASA Earth science research and remote sensing data.”³ Yet again, there is no reason to hide the pioneering role that was played by Hungarians.

In the Autumn of 1995, Dr Elizabeth Moore from the Department of Art and Archaeology, School of Oriental and African Studies, University of London, visited the JPL on behalf of the Royal Angkor Foundation (Budapest). During the following years, Dr Moore developed a particularly fruitful research cooperation with JPL on the application of radar imagery to scientific studies on the prehistory of Angkor, with the application, among others, of the 3-component scattering model developed by Dr Freeman and Hensley Scott, to prehistoric mounds in the Angkor region.

For 5 years, the radar project had remained the only effort to interpret the SIR-C/ X-SAR radar at an archaeological site in Southeast Asia. The radar, as interpreted by Dr Moore and her research partners at the JPL, offered particularly innovative views of the prehistoric sites in the Angkor area. Actually, in my view, they laid down a solid foundation for a new era in the application of radar imagery for archaeology.

2.2. The classical images of SIR-C/X-SAR

An image was acquired by the SIR-C/X-SAR on the 15th orbit of the space shuttle Endeavour on 30 September 1994. (There was another data-take in April 1994, however, that missed the target, and mainly covered the southeastern part of the Tonle Sap area. Nevertheless, that information remains important for a comparison of dry and rainy season shorelines of the Great Lake, and perhaps for many more.) The image shows an area approximately 55 km by 85 km that is centred at 13.43 degrees North and 103.9 degrees East. The image is usually called today as the “classical” radar image of Angkor in related literature.

2.2.1. 1994 – the 1st Phase by Discovery

Once again, it is not the intention of the author to describe the SIR-C/X-SAR technology,⁴ or the technical problems related to its application for archaeological or cultural resource management purposes. For the sake

³ Source: <http://spatialnews.geocomm.com/dailynews/2005/mar/02/news6.html>

⁴ See Anthony Freeman, *What is Imaging Radar?* at <http://southport.jpl.nasa.gov/index.html> Last updated: 26 January 1996.

of this article I wish to point out that the “classical” radar image of Angkor is a combination of the measured “backscatter” data from three radar wavelengths.⁵ The colours in that image were obtained using the following radar channels: red represents the L-band (horizontally transmitted and received); green represents the L-band (horizontally transmitted and vertically received); blue represents the C-band (horizontally transmitted and vertically received).

This image still remains my favourite. It is still a great challenge to interpret, and a great deal of research problems have never been addressed yet. What do we see on this image, or what *set of physical characteristics* of the ground are visualized on the image? How far is it worth to study the anomalies on the image? Are sharp differences of areas without any easily recognizable differences on the ground simply products of irrelevance for archaeological phenomena (such as the temporary dielectric constant of soil moisture)?

Certainly, I consider it vital to identify, geo-reference and ground-check the anomalies that would lead to the discovery of unregistered temples, monuments, artificial watertanks or *barays* under the vegetation canopy, in the Angkor area, or under the arid sand of the desert, anywhere else in the world. However, the real challenge, as I see it, is to find those sets of physical characteristics that might indicate the long-term presence of certain natural conditions, i.e. *the physical reminiscences of an historical period*, or the presence of major human intervention in general. That is what I call the “human fingerprint”.

While my suggestion regarding the quest for a definition of the “human fingerprint” in a particular natural environmental set-up might be only a mirage today, it might turn into hard evidence tomorrow. Nevertheless, if one would just read the list of the fields of application for radar imagery that have already produced a great deal of scientifically sound results in other fields of research, one might be able to understand my fascination with the application of radar technology to large scale areas of the Earth surface. I am sure that in the future it will be possible to *separate human and natural processes “vertically”, i.e. in time, or “horizontally”, i.e. in space*. Such sets of characteristics are represented on the images by “anomalies”, i.e. by physical “abrasions” on or subsurface features.

A valid question may arise, however, if most of the data would turn out to be too site specific or too general: for what scientific purpose would it be useful to collect, consolidate or simply process such an enormous amount of data? My answer to that is simple. We do not know what sort of fertile interrelationship might become evident, for whom, when and in relation to what sort of scientific question, until we have that sort of “macro-database” constructed. However, I am convinced by the developments of the last decade that such an opportunity shall definitely produce sound scientific results that cannot be achieved by any other method. It depends on who, when and for what reason approaches the database. In the conclusion I will come back to this point.

Preliminary tests of Dr Moore, Freeman, Scott and Kuszinger ought to be followed by others to differentiate or *automatically* compare datasets produced on different wavelengths and polarizations, rather than only gaze at the images themselves. Actually that is exactly what happened when the polarimetric and interferometric AIRSAR data were combined by Scott Hensley, as I will shortly describe.⁶

During my research I noticed that *separation*, i.e. visualization of each logical or technological option, will show different “anomalies”. Anomaly in this case means visual representation of not yet identified objects or phenomena (like moisture content) on the image. This is of particular value when we are not sure what actually we see on the image. Certainly, without verification on the ground it is very difficult to define the character or the cause of the anomaly. Nevertheless, I would come back to this point when I try to sum up the consequences of the individual application of the GIS and RS technologies for archaeological and cultural resource management (CRM) purposes.

⁵ The SIR-C/X-SAR antenna structure actually consists of three individual antennas, one operating at L-band (23.5cm wavelength), one at C-band (5.8cm wavelength) and the third at X-band (3cm wavelength). The L-band and C-band antennas are constructed from separate panels that can measure both horizontal and vertical polarizations. Source: <http://www.op.dlr.de/ne-hf/projects/sircdesc.html>

⁶ A brief explanation of the technology is given by Bruce Chapman: “The L-band and C-band antennas are constructed from separate panels that can measure both horizontal and vertical polarizations. [...] These vertically- and horizontally-polarized transmitted waves will be received on two separate channels, so that SIR -C will provide images of the magnitude of radar backscatter for four polarization combinations: HH (Horizontally-transmitted, Horizontally-received), VV (Vertically-transmitted, Vertically-received), HV, and VH; and also data on the relative phase difference between the HH, VV, VH, and HV returns. This allows derivation of the complete scattering matrix of a scene on a pixel by pixel basis. From this scattering matrix, every polarization configuration (linear, circular or elliptical) can be generated during ground processing. The radar polarimetric data will yield more detailed information about the surface geometric structure, vegetation cover, and subsurface discontinuities than image brightness alone.” Source: NASA SIR-C/X-SAR, manuscript, last update on August 25, 1994. <http://www.op.dlr.de/ne-hf/projects/sircdesc.html>

2.2.2. 1998 – the 2nd Phase by AIRSAR⁷

Parallel to the development of spaceborne imaging radars, NASA/JPL have built and operated a series of *airborne* imaging radar systems. NASA/JPL maintains and operates an airborne SAR system, known as AIRSAR/TOPSAR, which flies on a NASA DC-8 jet. In one mode of operation, the AIRSAR/TOPSAR system collects all *four polarizations* (HH, HV, VH and VV) for *two frequencies*: L-band ($\lambda \sim 24$ cm); and P-band ($\lambda \sim 68$ cm), while operating as an interferometer at C-band to simultaneously generate *topographic height* data. Typical image sizes for AIRSAR/TOPSAR products are 12 km x 12 km, with a 10 m resolution in both dimensions. Topographic map products generated by the TOPSAR system have been shown to have a height accuracy of 1m in relatively flat areas, and 5m height accuracy in mountainous areas.⁸ (However, in Angkor that accuracy was not demonstrated, since the 65 m high tower of Angkor Wat was measured at 27 m. Nevertheless, as we will see, it is not vital yet, and will be available soon.)

The images prepared by AIRSAR/TOPSAR on Angkor produced a major breakthrough again regarding future applications of radar in archaeology. Why do I call it a “major breakthrough” or what is the content of such a qualification? I consider it a breakthrough because the height data produced a radar image that made the Kapilapura mound, at the North-Eastern corner of Angkor Wat⁹ clearly visible, which was not recognizable on the previous “2-dimensional” radar image. We might call this the second, “classical” radar image of the Angkor area for archaeological purposes.

The AIRSAR data was further fine-tuned by Scott Hensley who generated combinations of the polarimetric and interferometric data to create images that were *sensitive to different features on the ground*.¹⁰ Again, for the purposes of this article I consider it important that different combinations of technical capabilities presented to the archaeologist generated new research objectives, which in turn, made it possible to “discover” sites, otherwise only known to local village inhabitants. Not the discovery in itself, but the co-operation and application of certain technological options as a result of that co-operation is worthy of our attention, plus the ability of the technology to scan large, otherwise inaccessible areas for similar features, if those sets of characteristics are well-defined.

2.2.3. 2000 – the 3rd Phase by Dr Roland Fletcher

Once again, for the purposes of this article, it is best to quote the short description of the “Greater Angkor Project” by its leader, Dr Roland Fletcher:

In September 2000 NASA/JPL, as part of PACRIM 2, carried out a comprehensive, detailed aerial radar survey of the environment and cultural landscape of the World Heritage site of Angkor in Cambodia. The survey was for a joint research project of the University of Sydney with APSARA (Royal Cambodian Government agency responsible for Angkor) and the Ecole Francaise d’Extreme Orient in association with World Monuments Fund and the Mekong River Commission.

This is the first comprehensive, consistent and detailed record of the whole of Angkor and its surrounding region. The project is investigating 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 regional ecosystem, sustainable development and the management of Angkor as a national and an international cultural resource.

The Archaeological Computing Laboratory is playing a key participatory role in this project. Ultimately, we hope to contribute to methodological developments for studying large-scale pre-industrial urban societies, including the use of GIS (Geographical Information System), remotely sensed data, computerised mapping applications, 3D imaging and visualisation.

The technical improvement, as I see it from the above description, is in the “computerized mapping applications”. However, what is even more important is the emerging integrated knowledge “platform” or the “virtual mindscape”, to distort the expression of Dr Moore.

⁷ From this phase onwards, the Hungarian research involvement had become collateral. However, the author was able to follow developments thanks to Dr Elizabeth Moore. I would like to use this opportunity to express once more my most sincere gratitude to her.

⁸ See Freeman, at <http://southport.jpl.nasa.gov/index.html>

⁹ See: <http://www.jpl.nasa.gov/releases/98/angkor98.html>

¹⁰ See: <http://photojournal.jpl.nasa.gov/catalog/PIA03871> and [PIA03867-70](http://photojournal.jpl.nasa.gov/catalog/PIA03867-70)

3. The horizontal dimension

I will call the “horizontal dimension” of research the efforts to standardize the “vertical” applications that are useful for a whole range of similar sites. It does not mean an automatism but a careful choice of a common denomination that produces a critical number of involved sites to produce a new dimension of understanding about the standard set of values present at those sites.

3.1. The swath and the data-takes

When I first received the 5-6m long scroll of the full black and white view image of the dataset, I was shocked by the accidental coverage of it. The width of the area mapped out by the radar was about 35 km, and the length was about 2500 km, stretching from the delta of the Mekong up to the northeastern highlands of the Korat Plateau in Thailand. For a great part, the image, by chance, followed the Mekong river valley. The intention of the NASA/JPL scientists was that “[d]ata from SIR-C/X-SAR will be used *to develop automatic techniques for extracting information from radar image data*, in preparation for the EOS SAR mission later in the decade.”¹¹

These experiments could lead researchers towards the identification of the processes of horizontal spread and range of certain types of human interventions that left their chronologically exact print on the natural environment. Dr Moore has achieved the best-known progress known to the author in this direction. She wrote her Ph.D. as early as 1988 about the moated sites in Northeast Thailand. Her research on curvilinear (circular and oval), later on rectangular, man-made structures has proved to be particularly fruitful for remote sensing, including aerial, satellite or radar imagery.¹² Her latest research will argue that the geometric forms, or more precisely, changes of the forms of manmade protective structures around settlements, might help us to identify chronological relations between them.

3.2. Pattern recognition – Heng Tung’s pigeon is back

If the relationships described above can be incorporated into algorithms, then they might lead to even more dramatic results in the pattern-recognized spread of certain types of human structures. Actually, the author tried to prove this in an incomplete Ph.D. thesis in 1998. In my outline, based on the research of Dr Moore and others, I described the probable relationship between the geometric forms as evidence of a transition from curvilinear pre- or proto-historic settlement structure in Angkor towards the rectangular *barays*, ponds or moats around towns, temples, shrines and other complexes.¹³

I asked experts at the Computer and Automation Research Institute of the Hungarian Academy of Sciences, Budapest, as early as September 1999, to try to run a pattern recognition search on a SIR-C/X-SAR C-band image. While the result was not published, it showed noticeable results. Again, what was not yet possible in 1999, seems to me to be possible very soon, as research in the field will provide more refined definitions for those “mystical” algorithms.

3.3. The World Heritage List

We have an ever-increasing number of sites that are particularly important for human civilization, collected and continuously updated on the World Heritage List of the World Heritage Convention, maintained by the World Heritage Center of UNESCO.¹⁴ While some sites from the 788 items of the List might profit from the technologies described above, at this point of our discussion I turn to a somewhat different aspect of the subject. Could those “micro-scale”, i.e. site-specific radar images, if collected together, provide a framework for a “macro-scale”, i.e. global archive of all sites with relevant archaeological (sub- or above) surface features?

¹¹ See Freeman, at <http://southport.jpl.nasa.gov/index.html>, italics by me.

¹² See Elizabeth Moore, *Spaceborne and airborne radar at Angkor: introducing new technology to the ancient site*, in James R. Wiseman and Farouk El-Baz (eds.), *Remote Sensing in Archaeology* (manuscript).

¹³ See János Jelen, Links between prehistoric and historic civilizations in Angkor (19 November 1998, ms).

¹⁴ Source: <http://whc.unesco.org/pg.cfm?cid=31>

Actually, the SIR-C/X-SAR technology can make that possible, since 80% of the Earth surface was collected into *one single radar image* by the NASA/JPL as early as 2003. Hence searching well defined “objects” or rather a set of characteristics “on the Earth’s surface” has become technically possible.¹⁵ However, is there any valid reason to do that? In my opinion the answer is yes. We might not yet agree on a clear archaeological research goal today, but we will surely do tomorrow. Hence it is worth finding a minimum useful set of features to test this. The World Heritage List is such a target. We could call that a CRM application, since the most self-evident use of the data could be incorporated into the process of periodic reporting. However, that is not the only CRM application one can imagine, just the most direct one.

3.3.1. Periodic Reporting – ZEMP-ing the WHL?

What is a periodic report? The World Heritage Center of UNESCO defined it as follows:

Periodic Reporting is intended to serve the following purposes:

To provide an assessment of the application of the World Heritage Convention by the State Party;

To provide an assessment as to whether the World Heritage values of the properties inscribed on the World Heritage List are being maintained over time;

To provide up-dated information about the World Heritage properties to record the changing circumstances and state of conservation of the properties;

To provide a mechanism for regional co-operation and exchange of information and experiences between States Parties concerning the implementation of the Convention and World Heritage conservation.¹⁶

It is easy to recognize that all World Heritage sites contain a great deal of standard geographic information that may easily be geo-referenced, and thus incorporated into a geographical information system. Actually, most of the data already identified in the standard format, to be filled every six years by the member states of the World Heritage Convention, has a direct or indirect “GIS aspect”.¹⁷ Hence a symposium was organized at the annual meeting of the American Association for the Advancement of Science (AAAS) under the title “Global Monitoring of World Heritage Sites: Towards a Global Standard” on 16 February 2002. Co-Chairmen of the symposium were the author of this article and Diane Evans, from NASA JPL. The summary of the meeting was as follows:

Periodic Report on implementation of the Convention Concerning the Protection of the World Cultural and Natural Heritage is a strategic challenge for a whole range of applied sciences, in particular for remote sensing and GIS, as well as Cultural Resource Management in a truly global communication environment. From 690 sites already inscribed on the World Heritage List, 487 are being scrutinized on a regional basis during the first six years of the cycle (2000 to 2005). What happened to the sites after being officially approved to be of “outstanding universal value”? After 30 years of existence, the governments of 167 states agreed to look back and report on the status of their most precious sites. Hopefully a new strategic guideline, a standard for Heritage Impact Assessment, will emerge at the end of each 6-year cycle that ought to include recommendations on monitoring and change detection for preservation and development. Space sciences, specially Earth observation programs, including already available remote sensing & GIS applications, could not yet play the role they should to provide the desperately needed CRM tool for governments, municipalities, local communities, investors and developers who are all involved. Education, training and awareness raising for national and local authorities and experts are key to sustainable resource management. Research communities and universities should work in close cooperation with the key stakeholders for the benefit of all. Synergy of CRM, RS & GIS in a global Internet based environment should serve as a model for new site nominations as well as improve disaster-monitoring capacity for site managers and national authorities.

A lot has happened since then but the task is still the same as it is described above.

3.3.2. ESA, NASA, UNESCO and the World Heritage

As I have mentioned earlier, NASA has signed a Memorandum of Agreement with UNESCO just in March 2005. Co-operation among national space agencies or the international space research community has started already more than 3 years ago when UNESCO initiated it together with the European Space Agency (ESA).¹⁸ However, despite the media attention, the initiative seems to be still in its infancy, which is understandable since its broad (i.e. global) and at

¹⁵ Source: <http://photojournal.jpl.nasa.gov/catalog/?IDNumber=PIA03395>

¹⁶ Source: <http://whc.unesco.org/toc/main18.htm>

¹⁷ Source: <http://whc.unesco.org/pg.cfm?cid=58>

¹⁸ Source: http://www.esa.int/esaCP/ASEEVTNW9SC_index_0.html

the same time, narrow (i.e. site-by-site) approach quench each other. Nevertheless, it is worthwhile to read the initial description of the initiative, as formulated on 2 October 2001, since it has not been changed since:

A pilot project using space technology to monitor the gorilla habitat in Central/East Africa is being presented today by the European Space Agency (ESA) and the United Nations Educational, Scientific and Cultural Organization (UNESCO).

At the 52nd International Astronautical Congress, in Toulouse, France, ESA and UNESCO are presenting their new initiative on the monitoring of World Heritage sites using space technology, mainly Earth observation satellites.

Through this joint initiative, UNESCO aims to expand the sources of data that contribute to *an integrated World Heritage database* assisting the countries involved (State Parties in UN parlance) in improving the monitoring of World Heritage sites. The intention is to create *a new remote-sensing unit inside the UNESCO World Heritage Centre* as well as a virtual network of co-operating entities, and to increase the capabilities in the areas of remote sensing and monitoring within State Parties, mainly in developing countries, will be enhanced.

UNESCO and ESA have agreed to establish an initial *framework of cooperation open to other space agencies and operators in the space field, and to start a pilot phase on a specific World Heritage site.*

This pilot project consists of a joint effort by UNESCO and ESA *to monitor the gorilla habitat in Central/East Africa.* The aims are:

- to test and select which space technologies are most appropriate for monitoring purposes;
- to demonstrate to both UNESCO Member States and the international community the feasibility of using advanced tools;
- to define the most adequate institutional and technical framework - such as the needs in human and project resources and the roles of the different partners.

The pilot project is likely to be expanded to cover selected World Heritage sites - both natural and cultural heritage sites.¹⁹

I am convinced that the previously described NASA and joint ESA and UNESCO initiatives demonstrate the broadening interest for an integrated database, an approach the author has been propagating since April 1996.

4. The future

*“We can know more than we can tell.”
Mihály Polanyi²⁰*

4.1. The tacit dimension of knowledge

The shortest and most reliable summary of the theory developed by Mihály Polanyi was delivered at a symposium on “Transcendence and Contemporary Culture” in 1968:

I look at my hand, another face, or a machine. I recognize its area by its enclosed contours, by the relation between the object itself and its background within my field of vision. While I attend to the object itself I am relying on multiple clues— shapes, colours, extensions, perhaps in changing relations to each other. But I do not focus directly on each aspect of the object in its field. I have awareness of many of these aspects of the whole. In the case of the human face I rely on an awareness of its many features for attending to the characteristic appearance of a particular physiognomy. Attending to the details implicitly while focally addressing myself to the whole, I integrate the features into the cast they jointly form. The act of perception, therefore, comprises two types of awareness. I have subsidiary awareness of multiple facial features while I integrate these aspects into the face as a whole to which I attend focally. I perceive things through the dual activity of subsidiary and focal awareness. This is, in outline, the theory of tacit knowing.²¹

If we are able to integrate the already available radar images of the Earth and individual images of certain locations, we might create a unique *framework for our “mindscape”*. Such a framework could actually contain access to regional images as well and to local points of interest. All that already exists, in the Planetary Photojournal of NASA for example, under the Earth, but only as separate “glossy” images, thus the “marginal focus”, so vital for new discoveries, is actually missing.²²

¹⁹ Source: http://www.esa.int/esaCP/ASEEVTNW9SC_index_0.html, italics by me.

²⁰ Source: Peter Smith (1983). *Tacit dimension*.

²¹ Source: Mihály Polanyi (1970). “Transcendence and Self-Transcendence” in *Soundings* 53:1, 88-94.

²² Source: <http://photojournal.jpl.nasa.gov/targetFamily/Earth>

4.2. Pattern recognition: the scale and spread of human intervention

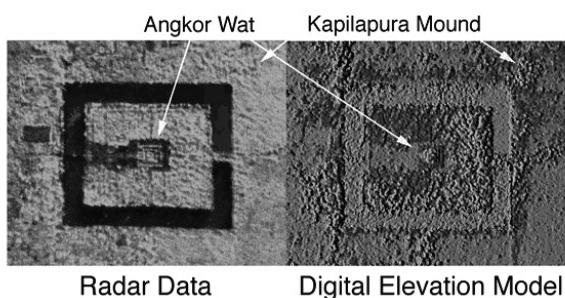
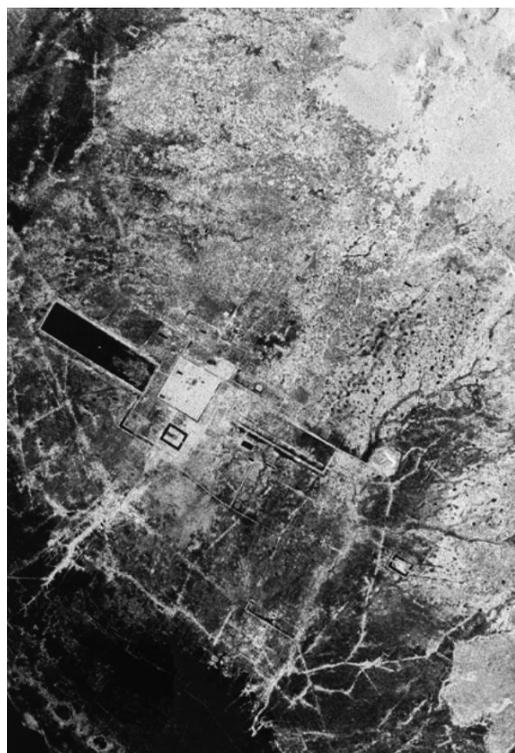
The time has come for efforts to identify the spread of certain man-made structures in a wider geographical context. Geometrical forms actually may reflect the presence of such interventions not only because nature rarely creates straight lines, circles, rectangles, etc. The process is just the opposite of that when such geometrical forms are abstracted. It seems to me that humans use forms to draw limits to the complexity of the nature that surrounds them. Our plans are based on our priorities *vis-à-vis* the structures, more precisely the functions of the structures to be built. Effort, i.e. energy we put into the implementation already reflects the importance of those limitations for the community as a whole that exercises them. A road always has a clear target where it leads to. However, whether we follow the shortest possible avenue to that target would depend on the importance and power, i.e. energy that we have at our disposal at that particular moment, for the construction of that road. If it is a ceremonial road that mainly has a symbolic importance, again, depending on the available resources, material, human, intellectual, and many more, we may invest great efforts into it to keep it straight. Certainly, this is also true if that road has vital military or economic importance. A rectangular *baray* in Angkor may be several kilometres wide and long, contain several million m³ water and clearly visible from space and still “just” reflect the universal power of a single monarch or the system that keeps him in that position.

Hence traces of those geometrical forms, partial or full, could lead us to discoveries of reflected efforts on a regional scale. Pattern recognition tools, among others, and radar technology, could be applied to huge surfaces of the Earth, even if those patterns show up only seasonally, through changes of vegetation or any other physical anomalies, like soil moisture content as in the case of Angkor. For example, strings of accumulated moisture under the surface of the ground show a perfect outline of the Hariharalaya *baray* of Indratataka. The river beds that have dried out a long time ago can be easily traced under the sand at Ubar or the Taklamakam (Gobi) desert. Here the novelty for archaeologists would lie in the fact that such a tool could search areas where archaeological excavations have never taken place or would not have been possible at all.

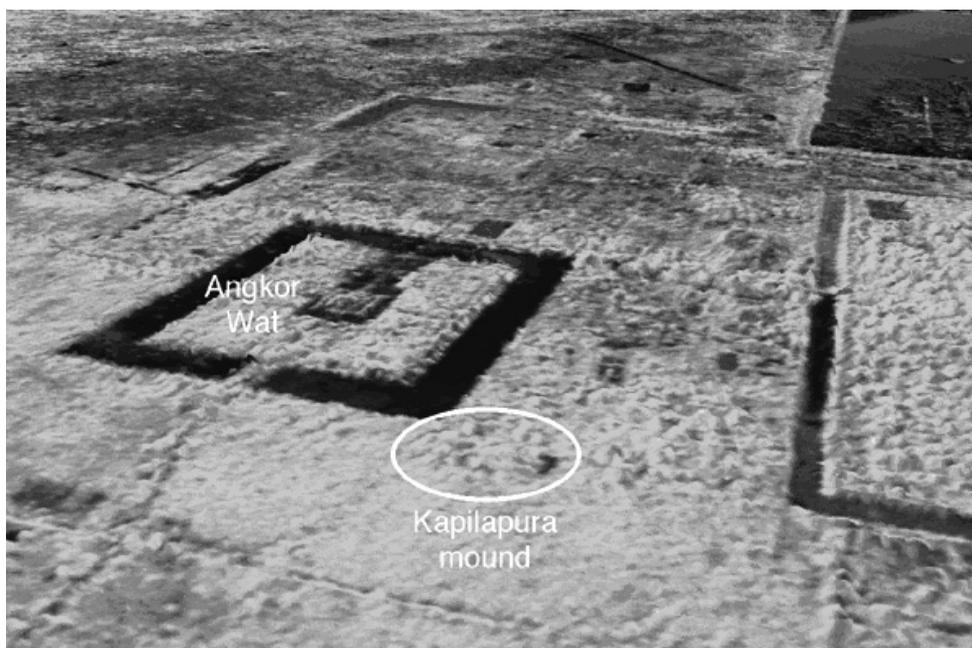
4.3. Stratigraphy or archive of discrete anomalies

The anomalies, more precisely the sets of anomalies I described earlier could in the very near future give to archaeologists a relative chronology for peeling overlaying complex periods of human interventions. When major interventions occur, the attitude towards the use of natural resources usually is also quite specific. Based on my limited experiences with the radar images of Angkor, I have the impression that selected colour shades might be associated with certain forms of human activities. That seems to be truly self-evident when we recognize certain cultivation types, but it seems to be also evident when we outline the area of a village. Here we cannot speak about the geometrical forms, but rather about a shade of colour, always at a certain wavelength, or RGB composite, or other technical parameters. If these parameters are kept in mind, we may build an archive of those anomalies, thus opening the way to a relative chronology.

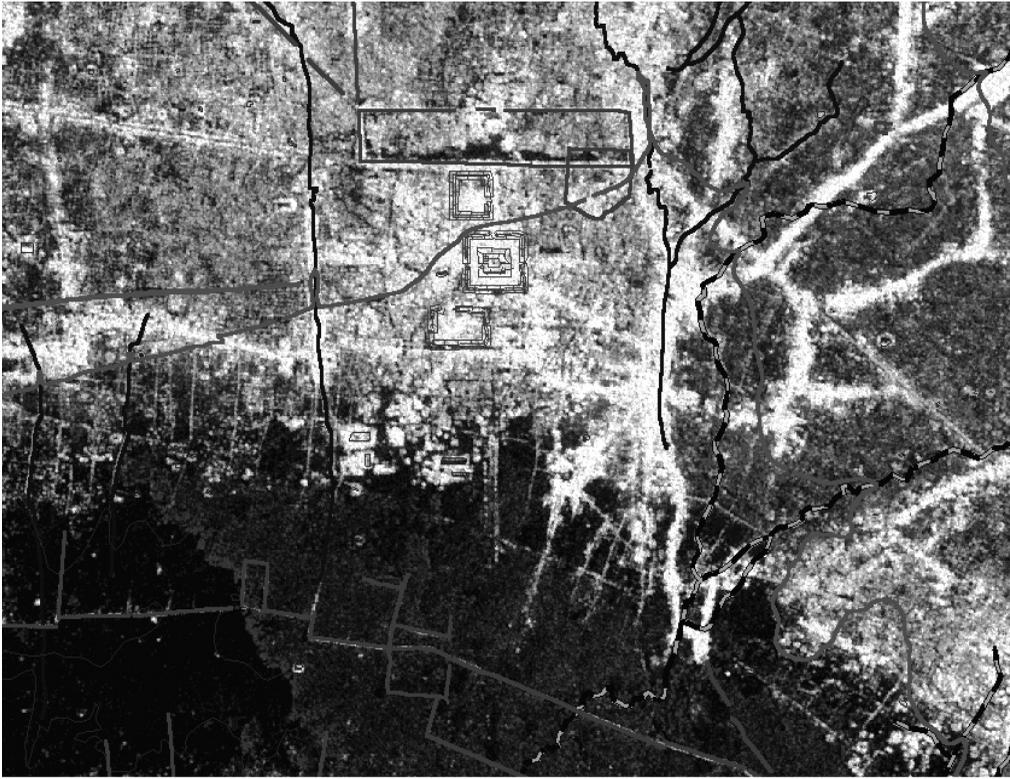
The “classical” radar image of Angkor. (The image was acquired by the Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) on the 15th orbit of the space shuttle Endeavour on September 30, 1994. The image shows an area approximately 55 kilometers by 85 kilometers that is centered at 13.43 degrees north latitude and 103.9 degrees east longitude. The colors in this image were obtained using the following radar channels: red represents the L-band (horizontally transmitted and received); green represents the L-band (horizontally transmitted and vertically received); blue represents the C-band (horizontally transmitted and vertically received). Courtesy to NASA/JPL. See: <http://photojournal.jpl.nasa.gov/catalog/PIA00505>



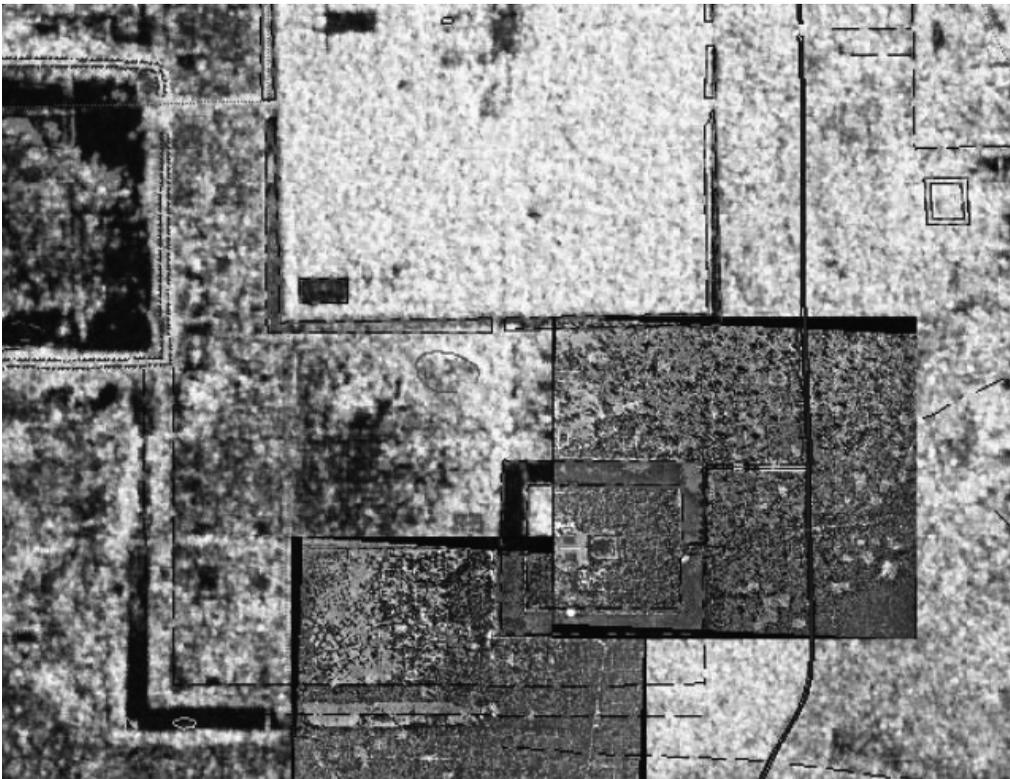
Kapilapura. This pair of images was created with data taken by NASA’s Airborne Synthetic Aperture Radar (AIRSAR) of the Angkor Wat temple area in Cambodia. The image on the left is a false-color radar image, while the image on the right shows topography data made while AIRSAR was being flown in its interferometric mode. Courtesy to NASA/JPL. See: <http://www.jpl.nasa.gov/releases/98/angkor98.html>



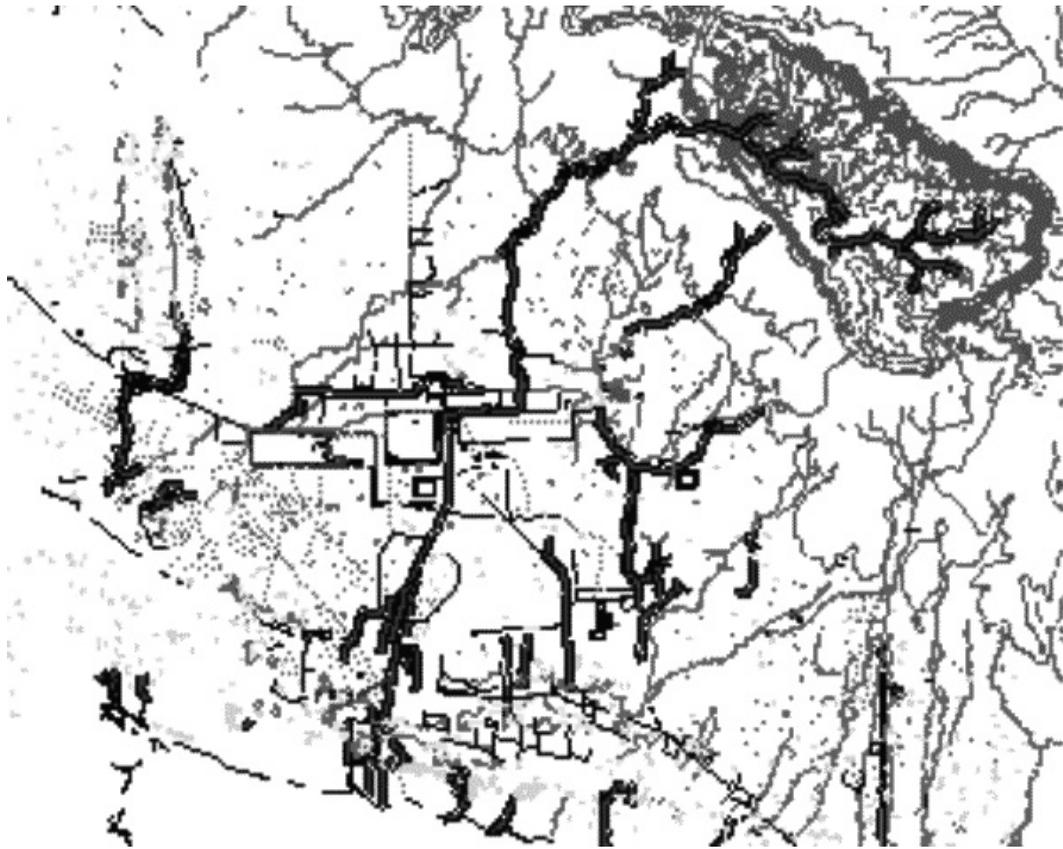
Angkor Wat & Kapilapura. This three-dimensional image was created with data taken by NASA’s Airborne Synthetic Aperture Radar (AIRSAR) of the Angkor Wat temple area in Cambodia. Height data generated using radar interferometry, a technique pioneered by JPL that combines two radar images, was used to simulate this perspective view. Courtesy to NASA/JPL. See: <http://www.jpl.nasa.gov/releases/98/angkor98.html>



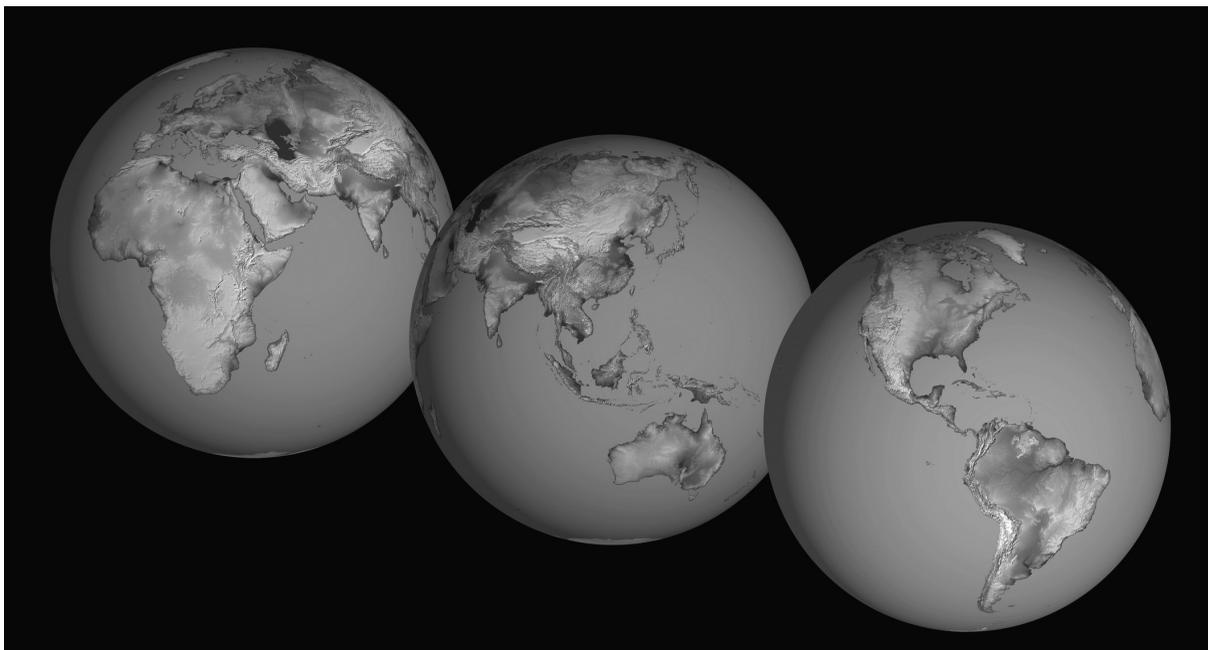
Hariharalaya I. The base image is an enlargement of the area from the “classical image” with interpretative layers based on early topographical maps, on ground measurements, hydrographic data, etc.



The image reproduced from AGIS-2 is a composite of the central area of Angkor that includes Angkor Thom, Angkor Wat, part of the Western baray, etc. Some parts are overlaid with aerial photos from the 1945 Williams-Hunt Collection, adjusted to the radar image plus the interpretation lines of some hydrological and historical structures. The base of the image the SIR-C/X-SAR “classical image”. (See above.)



The image is a result of analysis derived from all available sources available in AGIS-2.



These images of the world were generated with data from the Shuttle Radar Topography Mission (SRTM). These images were created from that data set and show the Earth as it would be viewed from a point in space centered over the Americas, Africa and the western Pacific. Elevation data used in this image were acquired by the Shuttle Radar Topography Mission aboard the Space Shuttle Endeavour, launched on Feb. 11, 2000. SRTM used the same radar instrument that comprised the Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR) that flew twice on the Space Shuttle Endeavour in 1994. Courtesy to NASA/JPL. See: <http://photojournal.jpl.nasa.gov/catalog/PIA03394>.

