EARTH OBSERVATION FROM SPACE FOR THE PROTECTION OF UNESCO WORLD HERITAGE SITES: DLR ASSISTING UNESCO

Mario Hernandez[a], Ulrich Huth[b], Gunter Schreier[b]

[a]UNESCO, Paris, France ; [b]DLR Cologne, Oberpfaffenhofen, Germany

KEY WORDS: Remote Sensing, Cultural Heritage, Archaeology, Monitoring, SAR, Satellite

ABSTRACT:

The United Nations Educational, Scientific and Cultural Organization (UNESCO) has established an operational network of space partners with key space agencies, space research institutions and universities in order to assist developing countries on the monitoring of the famous and prestigious World Heritage sites. This "open initiative on the use of space technologies to support the World Heritage" is supporting UNESCO in detection and prevention of threats to the world's extraordinary natural and cultural wonders, including uncontrolled agriculture, urban development, natural catastrophes, climate change, and excessive tourism. Therefore UNESCO and space agencies are bringing data together from satellite images, airborne data and ground measurements to assist UNESCO Member States in monitoring our heritage and precious resources. Satellite images, for the first time, allow generating accurate maps for protected areas in Central Africa or for the Great Wall of China. Very high resolution earth observation data has been used jointly by the German Remote Sensing Data Center (DFD-DLR) and UNESCO in order to preserve and monitor looting at archaeological sites in Iraq.The German Aerospace Center (DLR) has joint the UNESCO open initiative in particular contributing data from its new X-Band SAR satellite TerraSAR-X, as well as other mission data. With its medium and very high resolution (approx. 1m) and its day/night, cloud penetrating and interferometric capabilities SAR technology is specifically suited to monitor certain endangered World Heritage Sites and to perform research in archaeology. This paper provides a brief overview of the UNESCO World Heritage Programme, outlines the open initiative and the applicability of space borne data to assist in the preservation of the world heritage sites. It particular focuses on applications with high resolution SAR data and features endangered sites acquired in the various TerraSAR-X imaging modes, giving also a status on applications in this domain. An outlook to future applications in this domain is given.

1. INTRODUCTION

In 1972 a large number of countries committed to the conservation of those sites in the world that are of outstanding universal value from the point of view of culture, history, science, conservation or natural beauty, got together at the time of the 16th session of the UNESCO General Conference in November 1972, to adopt the World Heritage Convention. For more details see http://www.unesco.org/whc. Today, the Convention, under administration of UNESCO, is a success. As per October 2007, 185 State Parties are Parties to the Convention. These State Parties get together at least twice a year in the meetings of the Bureau and the Committee to approve new inscriptions of sites, to review the state of conservation of the inscribed sites and to agree upon on various other actions dedicated to the conservation of the 851 World Heritage sites that are inscribed today (as per October 2007) on the World Heritage list.

The countries that have ratified the UNESCO World Heritage Convention consider that it is essential to adopt new provisions to establish an effective system of collective protection of the cultural and natural heritage of outstanding universal value, organized on a permanent basis and in accordance with modern scientific and technical methods

The most significant feature of the 1972 UNESCO's World Heritage Convention is that it links together in a single document the concepts of nature conservation and the preservation of cultural properties. The Convention recognizes the way in which people interact with nature, and the fundamental need to preserve the balance between the two.

The Convention defines the kind of natural or cultural sites which can be considered for inscription on the World Heritage List.

The Convention sets out the duties of States Parties in identifying potential sites and their role in protecting and preserving them. By signing the Convention, each country pledges to conserve not only the World Heritage sites situated on its territory, but also to protect its national heritage. The States Parties are encouraged to integrate the protection of the cultural and natural heritage into regional planning programmes, set up staff and services at their sites, undertake scientific and technical conservation research and adopt measures which give this heritage a function in the day-to-day life of the community.

Each State Party to this Convention recognizes that the duty of ensuring the identification, protection, conservation, presentation and transmission to future generations of the cultural and natural heritage situated on its territory, belongs primarily to that State. It will do all it can to this end, to the utmost of its own resources and, where appropriate, with international assistance and co-operation, in particular, financial, artistic, scientific and technical, which it may be able to obtain.

2. THE UNESCO OPEN INITIATIVE

The countries that have ratified the UNESCO World Heritage Convention consider that it is essential to adopt new provisions to establish an effective system of collective protection of the cultural and natural heritage of outstanding universal value, organized on a permanent basis and in accordance with modern scientific and technical methods.

1972, the year when the World Heritage Convention was adopted by UNESCO was also the year when public remote sensing from civilian Earth observation satellites (i.e. Landsat) started in routine basis. Today more and more countries and organizations are keen to forge a close relationship between the global communities of World Heritage conservationists and remote sensing specialists.

To foster this objective, UNESCO and the European Space Agency (ESA) in 2001 agreed to undertake a joint initiative demonstrating the application of Earth Observation and other Space Technologies (e.g. Navigation and Positioning, Communication) in support of the goals of the World Heritage Convention, and to establish a framework of cooperation, open to Space Agencies, Space research organizations and universities (Hernandez, 2005).

Meanwhile, at the time of writing more than 20 national space agencies, 15 Universities, 4 earth observation companies and 6 congress/symposia have joint the initiative. More information about this initiative can be obtained under: http://www.unesco.org/science/remotesensing/

Under the umbrella of this open initiative several projects have been conducted to demonstrate the usability of space imagery and space technology to preserve our world heritage. Amongst them are:

- Develop a Decision Support System for Conservation of DRC World Heritage Sites
- Decision Support Tool for Gorilla Conservation in Central Africa
- Inventory and Preservation of Frozen Tombs in Altaï Mountains
- Biodiversity Conservation of World Heritage Parks of Iguazu and Iguaçu
- Decision Support System for Archaeological Sites in Guatemala
- Using Remote Sensing to Provide an Effective Management Tool for Machu Picchu
- Space Technologies to Assist Mesoamerica with the Biological Corridor

Results form these activities are also used for education among the youngsters: space is extremely attractive for the young generation and is an excellent tool to create awareness for conservation and sustainable development.

The German Aerospace Center (DLR) has a strong scientific and technological background in earth observation applications all over the globe. Amongst these applications have always been projects to monitor ecologic sites. Since the advent of very high resolution data and since the availability of very high resolution SAR data from DLR's TerraSAR-X satellite these projects are also focussing on historic sites and initiatives supporting humanitarian aid (e.g. the "Charter for Space and Major Disasters").

Therefore, since 2006 the German Space research Center (DLR) started working jointly with UNESCO and in 2007 it has become member of the UNESCO Open initiative in supporting UNESCO with DLR's space knowledge, earth observation data and expertise the conservation of our world heritage resources.

3. SATELLITE DATA SUPPORT PRESERVING ARCHAEOLOGICAL SITES – THE CASE OF URUK

Amongst the examples of DLRs' expertise and access to data supporting preserving the heritage of the mankind is a project performed in 2006 under the lead of the German Archeological Institute (DAI), together with other German partners and funded by the German Foreign Office (Schreier, 2007; van Ess, 2006). The DAI is maintaining historical sites and performing archaeological research tracing back to 1829. It works closely with local conservation authorities assisting them in their tasks. It therefore operates external offices in major countries of archaeological interest, amongst them the Baghdad office, founded in 1955 in order to support German research on historic sites in Iraq. One of these sites is Uruk, today named Warka and known as the biblical Erech. Uruk is situated c. 300 km south of Baghdad. It most probably evolved from two settlements situated on both sides of the Euphrates and which can first be attested around 4000 BC. The city rapidly grew into an integrated urban area, around 3000 BC covering its ultimately greatest expansion of 5.5 km^2. Therewith, the enclosed city of Uruk was the largest known in the ancient world until the 6th century BC, when the city of Babylon occupied an even larger area. Excavations by German missions, today based at the DAI, started in 1912. They are still on-going, but with interruptions since 2003. Up to date only 5% of the city was under research.

The historical city of Uruk is endangered by illegal digging and destruction by looting, as are many other sites in southern Iraq. As long as the security situation in Iraq remains difficult, it is not possible to study archaeological sites in Iraq on the ground. Therefore, the German Foreign Office funded a project to check the feasibility of using high resolution satellite IKONOS imagery to detect illegal digging. In addition, methodologies to support archaeologists in detecting so far unknown sites and to better map the extent of known excavations were tested. Older aerial photographs, a geographical information system (GIS) of so far unexcavated Uruk, elevation models and magnetic measurements have been used to help in estimating the state of preservation of archaeological sites and, in cases of unexcavated, destroyed sites, should deliver information about the kind of archaeological structures once present (Figure 1).

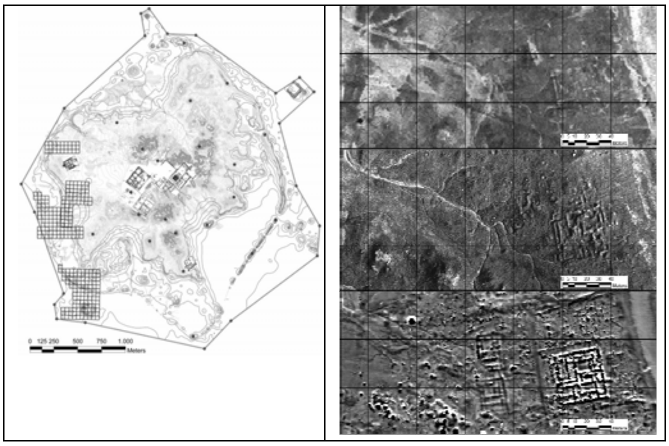

Figure 1. Available geospatial data for Uruk-Warka. Left side: Reference data (permanent geodetic points, contour lines, magnetometer grids, fence, maps). Right side: Comparison of image examples from different sources in the northern

geophysical survey area. Top: IKONOS satellite image, acquired on 07.09.2001, panchromatic band, Middle: aerial photography, Bottom: magnetometer measurement /image

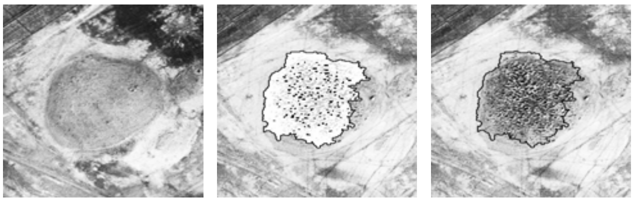

Figure 2. Archaeological site in 2001 (left) and in 2005 (middle and right) with individual looting sites and detected looting area

Object oriented knowledge based software was used to fuse all available information and to assist the archaeologists in extracting the relevant information. The Iraq pre-conflict – post-conflict comparison of IKONOS images indeed revealed looting activities at one site in the northern outskirts of Uruk. Looters dig in the sand and leave a series of traces: sand removal, wholes, car/track wheel-tracks, etc. The known characteristics of the looting were used to train the semi-automated image analysis software for use in locating so far undetected looting activities (Figure 2). Though limited by the amount of data and the time available for its evaluation, the study revealed that high resolution space imagery will be of great help in surveying cultural heritage sites and protecting them against damage.

4. TERRASAR-X SAR DATA IN SUPPORT FOR WORLD HERITAGE SITES

Based on the experiences with SAR (Synthetic Aperture Radar) technology from various ESA (European Space Agency) and German national SAR missions (SIR-C, SRTM) and based on economic feasibility and market studies, DLR and EADS/ASTRIUM signed a Public Private Partnership agreement, in March 2002, under which DLR orders from ASTRIUM the design, built and launch of an innovative X-Band SAR satellite, called TerraSAR-X. ASTRIUM contributes to the project in taking care for parts of the spacecraft costs and the development of the commercial market by its subsidiary InfoTerra, Germany (https://www.infoterra.de). In return InfoTerra receives the exclusive and global commercial exploitation of 50% of the capacity of the satellite. The other half of the satellite is exploited for science and non-commercial use by DLR thru international "Announcement of Opportunity" calls and thru special initiatives.

The satellite was launched on June 15th, 2007, from Baikonur, Ukraine with a Dnjepr-1 launcher in a 514 km dawn–dusk orbit. Just 5 days after the launch, the first SAR images have been acquired. After the commissioning phase, the satellite has started in January 2008 operational and regular acquisition of data for scientists and commercial customers worldwide.

The 1023 kg Terra SAR-X satellite delivers X-Band SAR data in various modes. The Spot-Light mode yields the finest resolution data with about 1m pixel size for a 10 km × 10 km image. The ScanSAR mode delivers 16 m resolution at 100 km swath. All imaging modes offer a full polarisation capability. A special "split antenna" mode allows experimental in-track interferometry, for instance for mapping moving objects.
The ground segment of TerraSAR-X is developed and operated by DLR in Oberpfaffenhofen and Neustrelitz (Moreira, 2007; Werninghaus, 2007).

Figure 3. Uruk-Warka as seen with TerraSAR-X Spotlight mode on November 30th, 2007

Already during the commissioning phase are few sites of interest for the world cultural heritage have been acquired amongst them also the archaeological site of Uruk (Figure 3) and such spectacular scenes as the pyramids of Gizeh. With the availability of very high resolution SAR (such as TerraSAR-X and CosmoSkymed; to be followed by other missions), new views to world heritage sites are possible not obstructed by cloud and weather conditions. Microwave technology also yields new results in the interpretation of the effects in scattering and interaction with the ground and vegetation. For instance longer wavelength radar is able to penetrate tropical foliage shielding ancient moments from a view from space. C-Band SAR (SIR-C) was already shown to slightly penetrate dry ground and therewith supported the finding of archaeological sites in Oman (SIR-C, 2006).

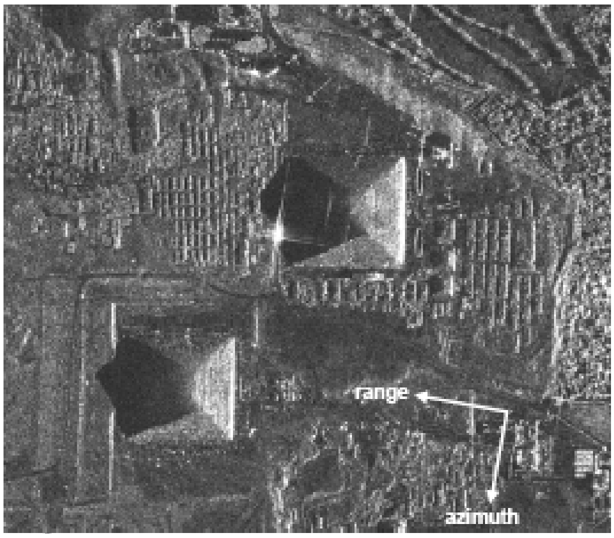

Figure 4. Great pyramids of Gizeh (on the Gyza plateau) as seen with TerraSAR-X Spotlight mode on July 2nd, 2007. The

side of the pyramid facing towards the satellite (range direction) is not geometrically compressed as could be expected.

It was the main pyramid of Gizeh which also verified a new geometric scattering effect in a very high resolution data take of TerraSAR-X (taken July 2nd, 2007). The space borne SAR was looking to one face of the pyramid with nearly the same incidence angle as this face is sloped towards the ground. Normal SAR imaging geometry would therefore expect a compression of this face of the pyramid to just a thin line in the image, an effect named foreshortening (Schreier, 1973). In contrast, it was shown that the pyramid looked like in ground projection (Figure 4). This effect was explained (Bamler 2008) by the staircase structure of the huge stones, being dihedral reflectors and thus creating a double reflection of the radar signal with the ground in front of the pyramid.

While this is a rather exotic effect in radargrammetry, it demonstrates that latest space borne imaging technology is not only supporting the protection of the heritage of mankind. One only remaining "wonder of the ancient world" also helped to better understand new radar imaging technology.

5. FUTURE APPLICATIONS AND PLANS

New high to very high resolution missions in both the optical and the microwave domain are now in orbit or will be operational in a few years (Schreier, 2005). Whilst the data is required for a multitude of environmental, planning and military applications (and henceforth available to normal users under commercial terms), the mission have often room to explore scientific domains and donate data to United Nations programmes and organizations such as UNESCO.

For DLR's TerraSAR-X mission, 50% of the satellite capacity is earmarked to be commercialized thru InfoTerra, while the remaining 50% is being distributed by DLR for non-commerical and science applications. Whilst this scheme is focusing on the tasking of new data, the entire TerraSAR-X archive is open to be exploited under both the commercial and the scientific regime. Remaining tasking capacity not occupied by commercial or science request can be used by the TerraSAR-X background mission. Some global objectives have been identified with this background mission. Amongst them is the global coverage of sites of interest. Under the signed open initiative, DLR and UNESCO have agreed to include in this background mission also a priority list of World Heritages Sites to be covered once or frequently (e.g. for sites endangered by slope movement such as Machu Pichu) during the mission duration of TerraSAR-X. Once data takes over these sites are in the DLR mission archive, this data be obtained for further scientific work and archaeological prospecting thru application to the TerraSAR-X science programme: (http://www.dlr.de/tsx/main/science_en.htm).

TerraSAR-X and high resolution SAR is just one example for a regular and organized coverage of world heritage sites. VHR data of the well known historic structures have been taken – if not for promoting the capabilities of the missions in stunning calendar images. But there is a need for a more coordinated approach and new frequency domains to be explored for archaeological investigations, such as long wavelength SAR and hyperspectral (Stuffler, 2007). Besides architectural heritage structures occupying a limited area (and covered by a single satellite image), large extent areas such as the Great Wall in China and the ancient Roman Limes, in Europe stretching from Scotland to the Black Sea, need to be covered. Cooperation amongst the mission operators in the supply of data and amongst international science teams would be required. This could either be a specific coordination with strong participation of UNESCO or a new task within the goals of the Group on Earth Observation (GEO).

REFERENCES

Bamler, R., Eineder, M., 2008. The Pyramids of Gizeh Seen by TerraSAR-X – A Prime Example For Unexpected Scattering Mechanisms in SAR, IEEE Geoscience and Remote Sensing Letters, in press.

Hernandez, M., 2005. *UNESCO and partners, an Open initiative on the use of space technologies for the conservation of natural and cultural heritage*, in: Use of Space Technologies for the Conservation of Natural and Cultural Heritage, Campeche, 28 November – 2 December, Mexico.

Moreira, A., Hajnsek, I., 2007: TerraSAR-X: Status Report and Polarimetric Data Exploitation. In: Proceedings of the International Workshop on Applications of Polarimetry and Polarimetric Interferometry (Pol-InSAR), ESA, International Workshop on Applications of Polarimetry and Polarimetric Interferometry (Pol-InSAR), Frascati, Italy, 2007-01-22 - 2007-01-26, ISBN 92-9291-208-7, ISSN 1609-042X.

SIR-C results on UBAR, 2006. under: http://www.op.dlr.de/ne-hf/SRL-1/p44414-ubar.html .

Schreier, G., Hernandez, M., van Ess, Margarete, 2007. Analysis of archaeological sites using remote sensing imagery; 32nd International Symposium, for the Remote Sensing of the Environment; San Jose, Costa Rica, June 25 – 29, 2007.

Schreier, G., Dech, D., 2005. High resolution earth observation satellites and services in the next decade – a European perspective, Acta Astronautica 57.

Schreier, G., 1993. Geometrical Properties of SAR Images in: G. Schreier (ed.), SAR Geocoding - Data and Systems, p 103-134, Wichmann, Karlsruhe.

Stuffler, T., et alii, 2007.: The EnMAP hyperspectral imager- An advanced optical payload for future applications in Earth observation programmes. Acta Astronautica, [61], S. 115 – 120.

van Ess, M., Becker, H., Fassbinder, J.,Kiefl, R., Lingenfelder, I., Schreier, G., Zevenbergen, A, 2006. Detection of Looting Activities at Archaeological Sites in Iraq using Ikonos Imagery Angewandte Geoinformatik; Beiträge zum 18. AGIT-Symposium, Salzburg, Wiechmann-Verlag, Heidelberg, p 668-678.

Werninghaus, R., Buckreuss, S., Pitz, W. 2007. TerraSAR-X Mission Status. In: Advanced SAR Workshop (ASAR), Advanced SAR Workshop (ASAR), Vancouver, Canada.