A STUDY FOR ARCHAEOLOGICAL EXPLORATION USING SPACEBORNE SAR

PI No. 308

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ABSTRACT

Two examples of ancient Egyptian ruins, Site No. 29 and Site No. 39, were discovered buried beneath the desert sands by using SAR data of JERS-1 and SIR-C[1],[2],[3]. Since both the discovered ruins were identified from the L-band HH polarization SAR, it is expected to be effective in searches for ruins within deserts. However, the L-band SAR observation parameters that contributed to the discovery of the two aforementioned ruins have yet to be sufficiently investigated; accordingly, this has become an important topic for research. This report describes the results of a field survey investigating the influence on detecting ruins of the SAR incident angle, the observation direction, and the soil moisture content, using data from PALSAR (L-band HH polarization) onboard the ALOS satellite.

1. INTRODUCTION

Egyptologists believe, according to the literature, that undiscovered pyramids and ancient ruins possibly remain buried somewhere beneath the desert sands. As noted by the Egyptologist Goneim, the discovery in 1952 of the buried pyramid of Sekhemkhet, an Egyptian Third Dynasty pharaoh, is a typical example. L-band SAR is known to be able to penetrate the sand layer of the extremely arid desert. In the field of archaeology, the most anticipated aspect of spaceborne SAR is the discovery of previously unknown ruins buried in the ground, and as a result of investigating the use of spaceborne L-band HH polarization SAR, two examples of ancient Egyptian ruins at Site No. 29 and Site No. 39 were successfully discovered buried in the desert at the Necropolis of Memphis. The discovery of these ruins demonstrates the effectiveness of detecting ruins in the desert by means of L-band HH polarization SAR onboard satellites.

However, the L-band SAR parameters that contributed to the discovery of the aforementioned ruins have yet to be sufficiently investigated, because new spaceborne L-band SAR required for validation experiments have not been launched since JERS-1 and SIR-C. In order to establish spaceborne SAR as an effective general system for detecting ruins, it is essential to clarify the relationship between the SAR system parameters and the target parameters of discovered ruins. Investigation of the SAR incident angle, which has been noted to have a great impact on the detection of ruins, is especially important.

According to this background, the ALOS PALSAR, launched in January 2006, is not only expected to clarify the relationship between L-band SAR parameters and the discovery of ruins, which is the subject of this research, but also considered to be a powerful tool for detecting undiscovered ruins since it has the newest high-performance sensors for L-band SAR, which were useful in the discovery of the abovementioned pair of unexcavated ruins.

2. METHOD

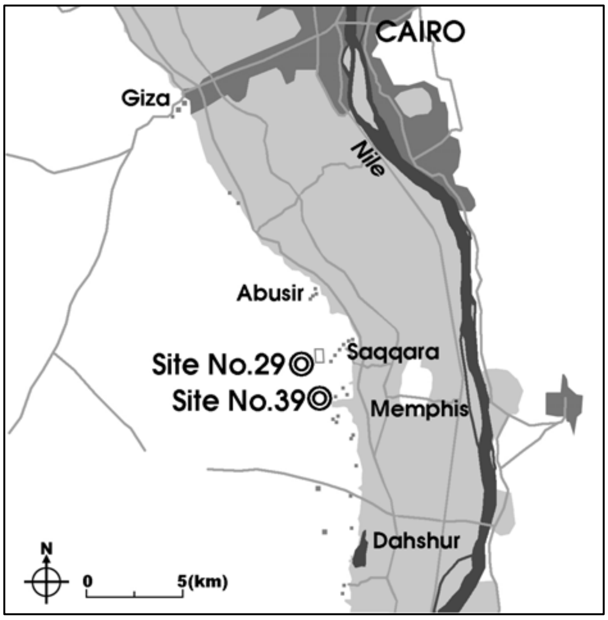


Fig. 1 Target area

2.1 Study Area

The target area for this research is the desert between Abu Rawash and Dahshur on the west bank of the Nile River. This region is commonly called the pyramid zone, which is centered on Memphis and has a high concentration of large structures, such as pyramids and mastabas, which were built during ancient Egyptian times. The Egyptian ruins discovered in this research are located in this region, which is a promising area for the discovery of additional sites. The study area for this research is shown in Fig.1.

2.2 Study Method

The two discovered ruins at Site No. 29 and Site No. 39 were used as the test site, of which spaceborne SAR images in the L-band with HH polarization were acquired. From these images, the effects of spaceborne SAR parameters on the detection of ruins were investigated. Specifically, through visual interpretation of L-band HH polarization PALSAR images obtained at different incident angles and observation directions, and with ground truth results of the actual ground structure, composition, and moisture content, the influence of each parameter on the search for ruins was investigated. PALSAR data observation was carried at the same time as ground truth.

2.3 Data Collection

Table 1. Collected L-band HH polarization SAR data

Satellite	Sensor	Acquisition date	Mode
ALOS	PALSAR	2006/08/12	FBS
ALOS	PALSAR	2006/08/14	FBS
ALOS	PALSAR	2007/01/28	FBS
ALOS	PALSAR	2007/07/27	FBS
ALOS	PALSAR	2007/07/31	FBD
JERS-1	SAR	1994/11/09	
JERS-1	SAR	1994/08/26	
Space Shuttle	SIR-C	1994/04/20	

The collected SAR data is given in Table 1. In regard to PALSAR, in order to investigate the influence of incident angle, observation data acquired at different off-nadir angles (50.8° and 36.9°, ascending mode) on August 12th and 14th, 2006, were selected. Furthermore, in order to investigate the influence of observation angle, observation data were acquired on July 27th, 2007 (off-nadir angle: 34.3°, descending mode). JERS-1/SAR and SIR-C data, which have already been proved effective in searches for ruins, were used here as reference data for validating the PALSAR results. In total, 5 scenes were collected, including those not involved with the ground truth. In order to investigate the relation between soil moisture content and SAR backscattering strength, ground truths of soil moisture content were carried out 4 times between February 2006 and July 2007. Of these, the August 12th and 14th, 2006, and July 27th, 2007, measurements were carried out simultaneously with PALSAR observations. The soil moisture content measurements were taken with a Trime-Como TDR portable soil moisture meter and recorded on a Datamark LS-2000. An overview of the ruins at Site No. 29 is shown in Fig.2, and the measurement equipment is shown in Fig.3

Fig. 2. General view of Site No. 29

Fig. 3 Soil moisture measurement device

3. Results

3.1 Influence of incident angle

PALSAR, JERS-1/SAR, and SIR-C images covering Site No. 29 and No. 39 are shown in Fig.4a)–h). According to previous observation results from JERS-1/SAR and SIR-C, Site No. 29 is identifiable in images acquired at JERS-1/SAR's off-nadir angle of 35.0° (Fig.4f) and g)), and Site No. 39 is identifiable in images acquired at only SIR-C's off-nadir angle of 61.5°. Hence, the incident angle is thought to have a strong impact on the detectability of buried ruins.

Fig.4a) and b) show PALSAR images observed on August 12th and 14th, 2006, at off-nadir angles of 50.8° and 36.9° (both with only HH polarization). Of these, vertical noise and ghosting phenomena stand out in the images acquired at the off-nadir angle of 50.8°. Generally, since L-band SAR can penetrate a layer of sand under arid conditions, the back scattering coefficient is small for empty desert, which appears dark in the images; on the other hand, the back scattering coefficient is comparatively large for most artificial structures such as buildings and roads, which appear light in the images. However, even large stone structures that are already known, such as the step pyramid at Saqqara (base = 121 m × 109 m, height = 60 m; see Fig.5) and attached facilities, which were built by the Third Dynasty pharaoh Djoser, are difficult to identify from images acquired at an off-nadir angle of 50.8°. On this point, PALSAR data obtained from an observation mode with an off-nadir angle of more than 41.5° suffer from range ambiguity due to the transceiver characteristics of the sensor, and it is considered that removing this noise is not possible.

From the above discussions, it can be concluded that PALSAR images acquired at an off-nadir angle of 50.8° are not suitable for detecting ruins in the Egyptian desert. On the other hand, at an off-nadir angle of 36.9°, known ruins could be identified, including the pyramid complex of the pharaoh Djoser. However, when limited to visual interpretation of images of Site No. 29 and Site No. 39, the underground structures are difficult to identify.

Nonetheless, the most well known of the large ruins, namely, the pyramids, are visible in the image acquired on July 31st, 2007, at an off-nadir angle of 34.3° (Fig.4e)). This data differs from other data in that the image was taken in the HH/HV fine beam double (FBD) polarization mode. A notable characteristic of this image is that the dynamic range is widest. For example, the maximum, minimum, average, and standard deviation of the back scattering coefficient in the range direction within 500 m of Dahshur's Red pyramid were 1.6 dB, -22.9 dB, -16.0 dB and 5.7, but 0.3 dB, -21.6 dB, -15.9 dB and 4.1 for data acquired previously on August 14th, 2006, respectively.

Here, as visually interpreted, the back scattering pattern is faint for the image acquired on July 31st, 2007, although the existence of Site No. 29 can be inferred (the lighter part at the top of the image). Regarding this, the influence of the observation direction will be discussed in the following.

3.2 The influence of illumination direction/Orientation

The illumination direction of JERS-1/SAR, which contributed to the discovery of Site No. 29, was approximately WNW (descending mode); however, the existence of Site No. 39 could not be identified from this image. On the other hand, the illumination direction of SIR-C, which contributed to the discovery of Site No. 39, was approximately SE (ascending mode), but the existence of Site No. 29 could not be identified. This is likely attributable to the influence of illumination direction of SAR. Let us now compare the observation data for both the ascending mode and descending mode.

According to past research, the range direction for the value of the maximum and standard deviation of the SAR back scattering coefficient and the residual scale of ruins are known to be correlated, with the ruins appearing larger as this coefficient increases. To determine whether Site No. 29 can be identified by PALSAR, the maximum and standard deviation of the back scattering coefficient are first compared with a region of desert that is known not to contain any artificial structures. Wadi Tafla (Fig.6), an arid valley in the Western part of the Memphite desert, was selected as the desert region for the comparison site. The results are shown in Fig.7. For the 500-m range in the vicinity of Site No. 29, the maximum and standard deviation of the back scattering coefficient for the range direction exceed the value for Wadi Tafla in the 2 scenes acquired by JERS-1/SAR and by PALSAR on July 31st, 2007 in the illumination direction of WNW (descending mode); therefore the existence of Site No. 29 can be identified from the PALSAR image of July 31st, 2007. Furthermore, the back scattering strength of Site No. 29 is slightly larger than the surrounding desert and is clearly visible in the image.

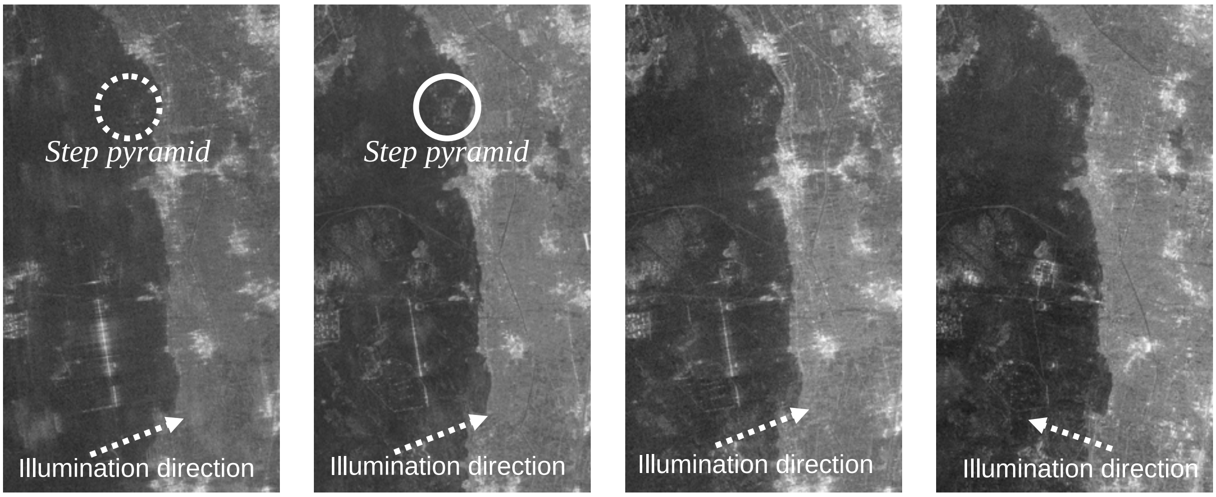
However, PALSAR image on July 27th, 2007 acquired in the illumination direction of WNW (descending mode) (Fig.4d)), the maximum value of the back scattering coefficient was only slightly higher, but the standard deviation was lower than that at Wadi Tafla. By visual interpretation, too, the existence of ruins was difficult. For Site No. 39, ruins were not discernable.

From the above, the ruins of Site No. 29 are identifiable from the 2 scenes acquired by JERS-1/SAR in the illumination direction of WNW (descending mode), as well as from scenes acquired on July 31st, 2007 by PALSAR in the illumination direction of ENE (ascending FBD mode). For this reason, the impact of illumination direction of SAR on the discovery of Site No. 29 is thought to be small. Yet, the reason for the difficulty in identifying the existence of the ruins at Site No. 29 from other PALSAR images, and the reason for the difficulty in identifying Site No. 39 from sources other than SIR-C, must be investigated.

3.3 The influence of target parameters

3.3.1 Soil moisture content

From February 21st, 2006, the soil moisture content of the target area was measured a total of 4 times. Of these, the 3 measurements on August 12th and 14th, 2006, and July 27th, 2007, were scheduled to coincide with PALSAR observations. The measured soil moisture content was in the range from 0% (Site No. 39: July 27th, 2007) to 6.3% (Site No. 29: August 14th, 2006). In the targeted desert area, the daily change in temperature and humidity is large, but a stable trend in soil moisture content can be seen (Fig.8).

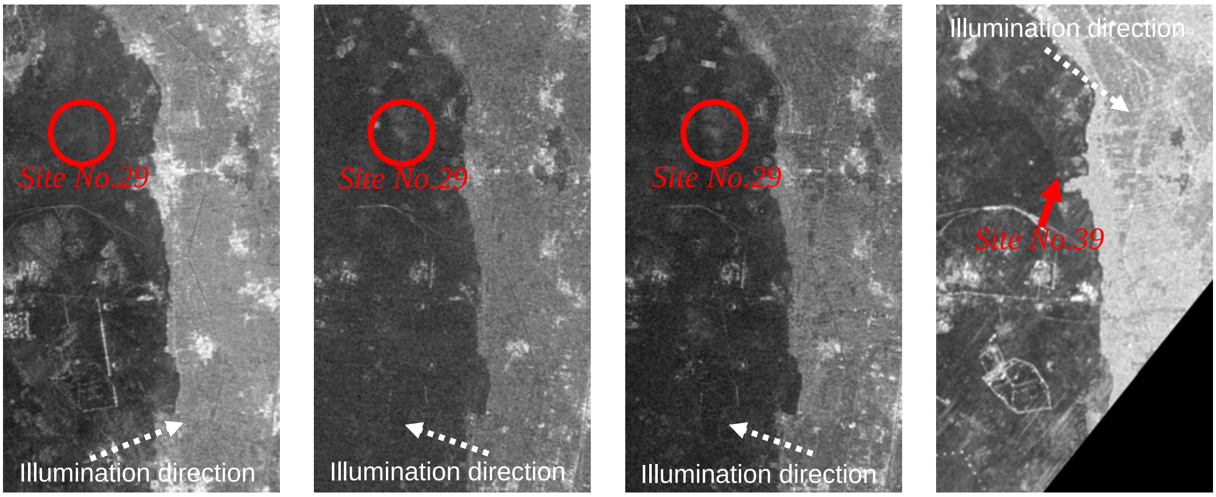


a) PALSAR
AUG/12/2006
20:43:19UT
23:43:19LT
Off nadir=50.8°
Ascending (FBS)

b) PALSAR
AUG/14/2006
20:26:18UT
23:26:18LT
Off nadir=36.9°
Ascending (FBS)

c) PALSAR
JAN/28/2007
20:25:50UT
22:25:50LT
Off nadir=34.3°
Ascending (FBS)

d) PALSAR
JUL/27/2007
08:23:51UT
11:23:51LT
Off nadir=34.3°
Descending (FBS)



e) PALSAR (HH)
JUL/31/2007
20:26:00UT
23:26:00LT
Off nadir=34.3°
Ascending (FBD)

f) JERS-1/SAR
AUG/26/1994
08:29:17UT
11:29:17LT
Off nadir=35.0°
Descending

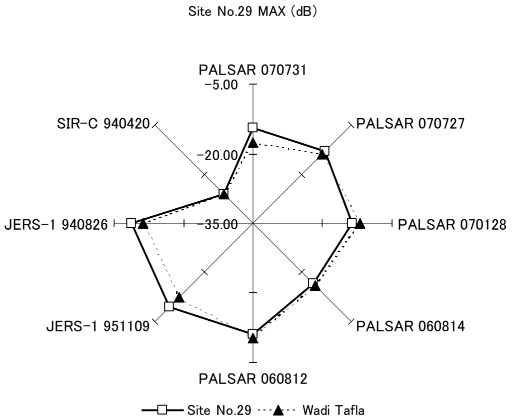
g) JERS-1/SAR
NOV/09/1995
08:37:30UT
10:37:30LT
Off nadir=35.0°
Descending

h) SIR-C (L band/HH)
APR/20/1994
00:05:49UT
03:05:49LT
Off nadir=61.5 °
Ascending

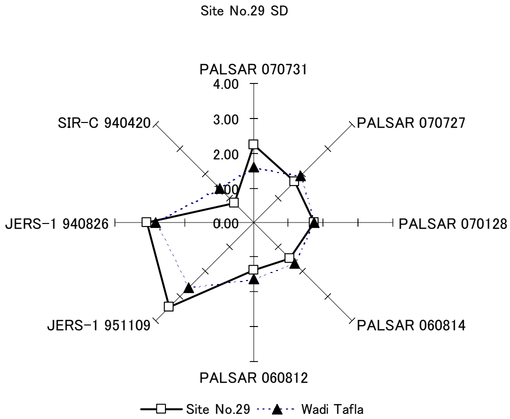
Fig. 4 Collected L-band HH polarization SAR data

Fig. 5 The pyramid of Djoser (Step pyramid)

Fig. 6. Wadi Tafla (Feb/21/2006)



a) Maximum value



b) Standard Deviation

Fig. 7 The maximum and standard deviation of the L-band HH polarization SAR back scattering coefficient in range direction for Site No. 29 and Wadi Tafla

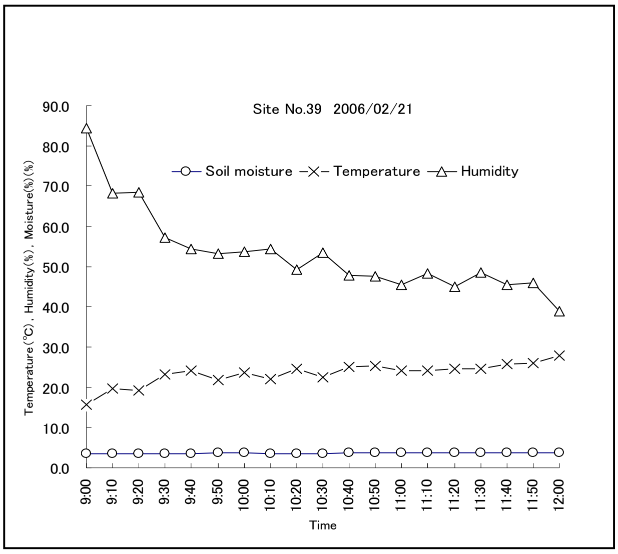


Fig. 8 Temperature, humidity, and soil moisture content within the target area (Site No. 39, February 21st, 2006)

3.3.2 Surface relics

At the surface of Site No. 29, many scattered relics, mainly pottery and stone fragments, can be found. The impact of the distribution of these surface objects on the PALSAR images was investigated by using the numerous verifiable pottery fragments at the ruins of the city of Buto (Fig.9, Fig.10), located at ancient city Mahmudiya to the north of Cairo, and in the ruins of the surrounding areas. Buto is considered an important archeological site, which played a leading role in the Nile Delta in the Predynastic Period, and the ruins are on a circular hill of approximately 1 km in diameter. Numerous fragments of pottery and of baked bricks are scattered on the site's surface, and the pottery appears to be of Roman/Byzantine origin. The back scattering characteristics at the site are shown in Fig.11. The back scattering coefficients of the pottery fragments are found to be extremely small, and thus the effect of pottery fragments on the detection of ruins at Site No. 29 is considered to be negligible.

4. Conclusions

In respect of possibility in detection of ruins using PALSAR images at Site No. 29 and Site No. 39, at least the existence of Site No.29 can be identified from the images acquired in FBD mode with HH/HV (HH polarization) on July 31st, 2007, although JERS-1/SAR was more effective at detecting ruins. On this point, a more detailed investigation is needed once new data is obtained. However, Site No. 39, discovered by SIR-C at an off-nadir angle of 61.5° (maximum incident angle), is difficult to identify from PALSAR at an off-nadir angle of 50.8°. Although there was a large influence of incident angle on the discovery of ruins at Site No. 39, owing to a problem with the PALSAR sensor characteristics, the clarity at this stage is considered problematic.

The relationship between the detection of ruins and L-band HH polarization SAR, which was involved in the discovery of the two aforementioned ruins, was investigated. Site No. 29 was identifiable in 2 scenes from JERS-1/SAR that were acquired in descending mode, as well as from PALSAR in ascending mode (July 31st, 2007), and thus the influence of the SAR observation direction on the discovery of the ruins is considered small. However, the reason why the same site could not be identified from PALSAR images acquired in descending mode, which had similar condition as JERS-1/SAR, is unclear at this time. This point must be re-examined with the addition of more data.

The relationship between the back scattering characteristics of PALSAR and soil moisture content must be examined further and include several ground measurements of the variously shaped objects at Site No. 29 and Site No. 39, such as the ruins, desert terrain, and rocks. Up to now, soil moisture measurements and the timing of satellite observations were set to coincide, which constrained the numbers of soil moisture measurements and measurement points at Site No. 29 and its environ had to be limited. However, the fluctuations in the time series of soil moisture content were less than expected, for example, the change in soil moisture content over 2 days at Site No. 29 was around 1.3%, and at Site No. 39 was around 0.5% to around 0.8% over a 14-h period; the other sites also showed similar trends. Therefore, temporal influences are not necessary to consider for soil moisture measurements, as long as there are no other causes of fluctuation on the day of satellite observation, such as rain. In the future, we plan to increase the number of samples to widen the scope of investigation.

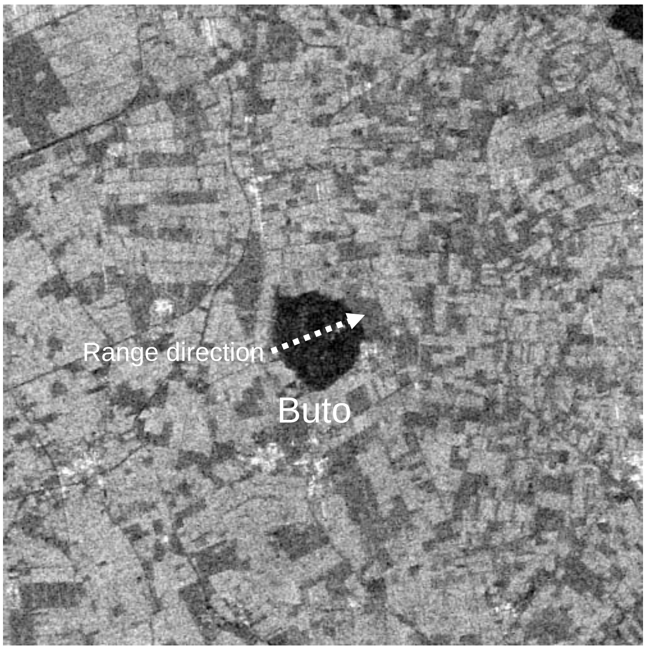
Also, investigation results of the ruins around Buto suggest that pottery fragments littering the ground at Site No. 29 have a negligible effect on spaceborne SAR observation. In other words, structures made of stone or scattered relics are still possibly buried at Site No. 29, and so we anticipate the results of an archaeological excavation of the site.

However, the data acquired in the observation mode at an off-nadir angle of >41.5° suffer from range ambiguity due to the transceiver characteristics of the sensors, which will make using PALSAR data acquired at large incident angles difficult unless improvements are made. The best results were obtained for the target area by using FBD in ascending mode; however, here is only limited data acquired by using FBD in descending mode, and more observations from descending mode are strongly needed so that the influence of observation direction can be evaluated more thoroughly.

Preparations are now underway to use spaceborne SAR to explore other areas. We plan to search for ruins in the Nile Delta and areas to the south, and to search for imperial tombs in China's Yellow River basin.

a) General view **b) Relics (fragments of red colored pottery)**

Fig. 9 Surface condition of the Buto site (Tell el-Fara'in)



a) QuickBird image :APR/18/2009
©DigitalGlobe/HitachiSolutions

b) PALSAR (HH polarization): **AUG/17/2007 FBD mode**

Fig. 10 QuickBird and PALSAR images of the Buto site

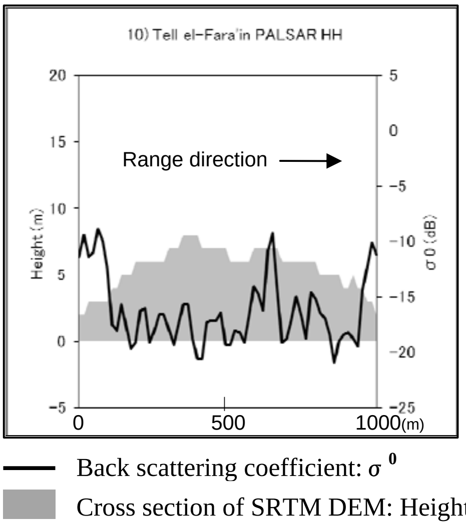


Fig.11 Relationship between back scattering coefficient of PALSAR (HH:AUG/17/2007) and cross section of SRTM DEM in range direction of approximately 1 km around the Buto site

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