Archaeological prospection in the Western Regions of Western Han Dynasty by satellite synthetic aperture radar data, case studies of Yumen Frontier Pass and Niya ruins

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Outlines

• Objective & background
• Problem definition
• Data processing methodology
• Case studies
• Perspective & conclusions
Research aim:

- common Italian and Chinese interests in obtaining advances, operative tools and technologies for the protection and enhancement of cultural heritage with particular reference to sites included in the UNESCO list.
- complementary skills which characterize the Italian and Chinese researchers involved in the current proposal with particular reference to the CNR (Italy Research Council) and the CAS
- the opportunity to share and use satellite data of Italian and Chinese space agencies
- the extraordinary cultural heritage witnesses of ancient civilizations in both countries
Silk Road is the witness of the Chinese prosperous civilization and the friendship between East and West. As an important component of the Silk Road economic belt, nowadays, archaeology for the Silk Road is confronted with challenges considering the diversity of its surrounding environmental and anthropogenic impacts.

Our study sites cover the original, middle and terminal section of the Land Silk Road.
Today, abundant multi-mode satellite SAR are available due to the technology development. SAR data for archaeology definitely has stepped into a golden era. However, compared with optical approaches, performance of SAR data for archaeological applications is not fully understood and needs further exploitation:

- Identification of regular, observable topological traces on the landscape, e.g. crop, shadow, soil and damp marks on SAR images
- The optimization of SAR image scaling contributes for cost-savings and for improving detection performance in archaeological applications
- The optimal geometry of SAR imaging (i.e. incidence angle together with satellite flight path) to sharpen the archaeological anomaly linked to backscattering.
- Landscape archaeology using median resolution SAR data
Data processing methodology

X,C,L-band SLCs

Radiometric calibration

Calibrated SLCs

Cosmo-SkyMed, TerraSAR, Sentinel-1

PALSAR

Co-registration Multi-looking
Enhanced Lee filtering

Resampled SLCs & MLIs

Multi-date analysis
- Interferometric coherence
- Image ratio
- Multi-date average
- RGB colour composition

Single-date analysis
- Flight pass
- Resolution
- Band

MLIs

Multi-looking Enhanced Lee filtering

Geocoded SAR/InSAR products

\[ \gamma = \frac{\sum_{n=1}^{N} s_{1n} \cdot s_{2n}^* \cdot \exp(-j\phi_{\text{flat},n})}{\sqrt{\sum_{n=1}^{N} |s_{1n}|^2 \cdot \sum_{n=1}^{N} |s_{2n}|^2}} \]

\[ R_{\sigma_i} = \frac{\sigma_i^0(t_k)}{\sigma_i^0(t_j)} \]

\[ \overline{\sigma_i^0} = \frac{1}{n_{t=t_0}} \sum_{t=t_0}^{t_n} \sigma_i^0(t) \]
### Case studies

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<td>PALSAR</td>
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Capability assessment of SAR remote sensing in Yumen Frontier Pass and its surroundings

Yumen Frontier Pass

Great Wall in Han Dynasty

Dunhuang city
Great Wall in Han dynasty disappear in both images, demonstrating the penetration capability of PLASAR is limited in this arid region with Yardang geological condition (compacted deposit surface layer with low porosity). However, more experiments are required for a comprehensive quantitative evaluation.
The linear archaeological feature of Han Great Wall were reflected more clearly on the ascending acquisition than on the descending one; this is probably due to the parallel flight path of the ascending acquisition compared with the direction of the Han Great Wall.
(a) Spotlight; (b) Stripmap. It indicates that higher resolution image is preferred for the identification of archaeological features referring to the high-resolution image from Google Earth (c).
Performance assessment of X-, C- and L-band SAR data (filtered by a $3 \times 3$ pixel enhanced Lee operators) in detection of Han Great Wall and Yumen Frontier Pass; (a) X-band Stripmap TerraSAR with a spatial resolution of 3m, (b) L-band PALSAR with a spatial resolution of 8 m and (c) C-band Sentinel-1 with a spatial resolution of 20 m.

Principles to select the optimal bands——X\C\L-SAR is sharpening the backscattering contrast between archaeological features and the surrounding landscape.
High coherence was observed in the rectangular man-made relic (Yumen Pass) caused by the invariable backscattering; in contrast, only partial linear archaeological features can be identified, e.g. Han Great Wall in (a) interpreted by the backscattering variation between two interferometric acquisitions and the decline impact induced by the coherence data processing. In the image ratio (b), we lose infos. For the multi-date average (c) and RGB composites (d), both the rectangular and linear shape archaeological features were clearly observed. The speckle noise has been mitigated in (c) by temporal averaging, and archaeological relics showed as a grey-scale due to the invariable backscattering in multi-temporal acquisitions.
Yumen Frontier Pass and its surroundings archaeology combining SAR and optical remote sensing

Great Wall

Posthouse
Detection the lost Yang Frontier Pass jointly by SAR and optical images

Will be validated by field campaigns with local archaeologists in future
SAR remote sensing for archaeology in Niya ruins
A linear feature was detected on the C-band Sentinel-1 data caused by the strong dihedral backscattering.
Invisible in optical, nonetheless, detectable in SAR owing to its penetration capability to extract infos from the subsurface

Ancient settlements locate on the right side of the suspected linear feature. We interpret it as the flood fortification
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<th>Difference (m)</th>
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<td><strong>Aver. 1.58</strong></td>
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The flood fortification was further confirmed by the height difference in the W-E direction, implying the ancient Niya River runs though the site on the West.
Multi-date processing of PALSAR in Niya ruins. (a) Coherence, (b) image ratio, (c) multi-date averaging, (d) RGB composition.

Ancient deposition was observed in (a). The spatial layout is consistent with archaeological features. Limited by the short-term interval, (b) demonstrated no signature. Deposition with archaeological ruins demonstrated bright backscattering in (c). (d) was beneficial to identify the spatial distribution of archaeological ruins, interpreted by the invariable backscattering.
The reconstruction of the paleohydrological system and uncovers its disappearance of Niya City-State abruptly after 500 A.D.

(A) Pan-sharpened Chinese GF-1; (B) color-shaded DEM from TerraSAR/TanDEM-X bistatic radar interferometry and (C) hydrological reconstruction combining (A) with (B)

70~80m burst gaps were observed on the reservoir, indicating the collapse of the paleohydrological system.
Perspective & conclusions

For the detection of traces of palaeo-environs and subsurface remains:

1) the analysis of the single-date scenes shows that all the sensors X-band Cosmo-SkyMed, C-band Sentinel-1 and L-band PALSAR were able to capture the traces of palaeo-river even covered by sand. This is due to the favorable conditions of terrain (mainly dry conditions and small grain size)

2) the analysis of the multi-date products shows that the interferometric coherence, average and RGB multi-date composition were able to identify unchanged areas linked to the presence of archaeological remains, whereas the ratio was unsuitable to detect any features significant for our investigations

For the identification of emerging earthen structures:

1) the analysis of the single-date scenes shows that only X-band Cosmo-SkyMed and L-band PALSAR were able to capture the section of the Great Wall and the Pass under investigation.

2) the multi-date products shows that the average and RGB composition were able to identify the Great Wall as well as the other man-made features present in the area of investigation; whereas both interferometric coherence and the ratio did not provide any significant results.
In this study, archaeological investigations in the Western Regions in Western Han Dynasty along the Silk Road, in particularly focusing on the Yumen Frontier Pass and the Niya ruins site, were conducted using X-band TerrraSAR and Cosmo-SkyMed, C-band Sentinel-1 and L-band ALOS PALSAR data.

Based on the packaged single-date and multi-temporal SAR data processing methods, the capability of prevalent spaceborne SAR data for archaeological prospection has been comprehensively assessed from aspects of spatial resolution, imaging geometry, bands, change detection and monitoring. Results highlight the potential and the need to make SAR operative for archaeological research, particularly as the implementation of the Silk Road Economic Belt (SREB) initiative gathers momentum over the coming years and decades.
Thanks!

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