Monitoring and detecting archaeological features with multi-frequency polarimetric analysis

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The idea behind – Aerial Archaeology

- Crop marks
- Damp marks
- Shadow sites
- Soil marks
SAR contribution in Archaeology

Nile river, IV cataract, Sudan

Space Shuttle

Dry environment

Subsurface penetration

Paleochannel

SIR-C/X-SAR image

Paleohydrology

10 km
The UNESCO World Heritage List

Gebel Barkal and the site of the Napatan Region
N 18 31 60 E 31 49 0

Sudan

Northern State, Province of Meroe
Date of Inscription: 2003

http://whc.unesco.org/en/list/1073

Napatan (900-270 BC) - Meroitic (270 BC 350 AD) cultures
Tombs, pyramids, temples, living complexes and palaces

- Soft nature of building stone
- Severity of local environments
- Long-term looting activity

Study area: Gebel Barkal
Study area: Gebel Barkal

- Nubian desert
- Archaeological area
- Palms cultivation
- Modern city

- Sand dunes (strong winds)
- Sandstone rocks
- Limestone rocks / Limestone building material
- Wind erosion/sand corrosion
Archived data

ALOS PALSAR
Ceased operation in 2011

L-band
Central Frequency 1.270 GHz
\( \lambda = 30 \text{ cm} \)
Spatial Resolution: 20m

Specifically acquired data

RADARSAT-2
(VigiSAT – BreTel) 2012-2013

C-band
Central Frequency 5.405 GHz
\( \lambda = 5.6 \text{ cm} \)
Ground Spatial Resolution: 11 m

Ground anomalies backscattering

Archaeological features

Morphological features
ALOS PALSAR - archived data

PAULI decomposition image

R: |HH-VV|
G: |HV|
B: |HH+VV|

ALOS PALSAR footprint

Fixed Incidence angle 26.07°

2006/08/14
2009/11/05
RADARSAT-2—specifically acquired data

**PAULI decomposition image**

- **R**: |HH-VV|
- **G**: |HV|
- **B**: |HH+VV|

**RADARSAT-2 footprint**

Not Fixed Inc. angle 27.06°

- **2012/04/28**
- **2012/11/06**
- **2013/01/17**
- **2013/07/07**
Polarimetric Data Extraction

Polarimetric decompositions (3x3 multilook)

Pauli decomposition

Combinations
H/A
H/α
Shannon H

Freeman Decomposition
Freeman 3 components

Yamaguchi Decomposition
Yamaguchi 4 components

PolSARpro

SLC level 1.1
ALOS PALSAR – Pauli decomposition

SLC level 1.1

Polarimetric Data Extraction

Pauli decomposition

2006/08/14

2009/11/05
ALOS PALSAR – Yamaguchi 4 decomposition

R: $f_{DB}$
G: $f_{VS}$
B: $f_{SB}$

2006/08/14

2009/11/05

Yamaguchi Y4O
Yamaguchi Y4R
Yamaguchi G4U1
ALOS PALSAR – Yamaguchi 4 decomposition

2006 $\theta = 26.70^\circ$

2009 $\theta = 23.10^\circ$

-16.99 dB  -13.01 dB

-10.27 dB  -6.77 dB

-20 dB  -16.99 dB

Double bounce  Single bounce  Volume scattering
ALOS PALSAR – Yamaguchi 4 decomposition

2006 $\theta = 26.70^\circ$

2009 $\theta = 23.10^\circ$

Double bounce: -16.99 dB, -13.01 dB

Single bounce: -10.27 dB, -6.77 dB

Volume scattering: -20 dB, -16.99 dB
RADARSAT-2 – Pauli decomposition

2012/04/28
2012/11/06
2013/01/17
2013/07/04
RADARSAT-2 – Yamaguchi 4 decompostion
Yamaguchi 4 decomposition

ALOS PALSAR 1.270 GHz

RADARSAT-2 5.405 GHz

Double bounce

Single bounce

Volume scattering
Dataset

**Archived data**
- **ALOS PALSAR**
  - 2006-2009
  - L-band
  - Spatial Resolution: 20m

**Specifically acquired data**
- **RADARSAT-2**
  - (VigiSAT – BreTel) 2012-2013
  - C-band
  - Ground Spatial Resolution: 11 m

- **SENTINEL-1B**
  - Jan 2016 – Dec 2018
  - C-band
  - Ground Spatial Resolution: 20m

Full mission data employed for time series analysis
Sentinel-1 preliminary analysis
Sentinel-1 preliminary analysis

S-1 Time series Average - Sigma0 VV
Sentinel-1 preliminary analysis

S-1 Time series Average - Sigma0 VH
Sentinel-1 preliminary analysis

Time series backscatter Sentinel-1 VV

- unknown
- Pyramid East
- Pyramid South
- desert

Sigma0 [dB]

Acquisition date

11 Jan 16 - 11 Dec 18
Sentinel-1 preliminary analysis

Time series backscatter Sentinel-1 VH

- unknown
- Pyramid East
- Pyramid South
- desert

Sigma0 [dB]

Acquisition date
Ground truth campaign

- Intervention plans
- Excavations plans
- Preservation activities

Courtesy of Prof. E. Ciampini
Ground truth campaign

- Complexity of data analysis and interpretation
- Spatial resolution for structures detection
- Site selection (topography, geomorphology, potential threats)

Courtesy of Prof. E. Ciampini
Conclusions and way forward

- Original use
  - High potential

  - Dry environments

- Surface penetration ($\lambda$)

- Multi frequency analysis

One possible combination

- ALOS PALSAR
  - Low spatial resolution
  - Deeper penetration

- RADARSAT-2
  - Medium spatial resolution
  - Lower penetration

- SENTINEL-1 Time series

More possible combinations

- Multi frequency
  - Multi incidence angle analysis
    (ALOS-2, SAOCOM, NISAR, BIOMASS)

Optical data integration and ground truth validation
Thank you!

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