Multi-temporal archaeological and environmental prospection in Nasca (Peru) with ERS-1/2, ENVISAT and Sentinel-1A C-band SAR data

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Region of Interest

Nazca civilization (200 BC – 600 AD)

- Cahuachi
- Atarco
- Nazca
- Rio Taruga
- Palpa
- Rio Palpa
- Rio Ingenio
- Nazca lines
- Cerro Blanco
- Rio Aja
- Rio Terras Blancas
- Rio Grande
- Rio Nazca
- Rio Las Trancas
- Tungua

Inset map showing location on South America.
Archaeological heritage

- Lines and geoglyphs of Nasca and Pampas de Jumana
- Ceremonial Centre of Cahuachi
- Aqueducts networks and drainage galleries (*puquios*) and reservoirs (*ojos*)
Climate conditions

**Nasca**

Climate: desert (Rio Grande valley)

Precip.: virtually no rainfall during the year (tot. 4 mm per year)

Temp.: 20.6°C (Palpa) and 20.9 °C (Nasca) on average (Feb.-Mar. the warmest; July the coldest)

**Palpa**

Source: http://en.climate-data.org
ESA & DLR Nasca projects

Project id.11073
Archaeological and environmental studies in the Nasca region (Southern Peru) using multi-temporal C- and L-band SAR imagery

Objectives

• Change detection (evolution of the Rio Nasca catchment basin)
• Archaeological surveying (*puquios*, buried structures)
• Ground and structural deformation analysis and looting monitoring
• Environmental assessment

ITACA – Italian mission of heritage Conservation and Archaeogeophysics

LASAPONARA & MASINI (2011)
ERS-1/2 SAR ImageMode
- 20 scenes, desc. (1992-2010)
- 80 scenes, asc. (2001-2011)

ENVISAT ASAR ImageMode IS2
- 5 scenes, asc. (2005-2007)

ALOS PALSAR scenes
- 3 FineBeam, Dual Pol. (2007-2008)

ASAR imagery
- Wavelength ($\lambda$): 5.6cm
- Frequency ($f$): 5.3GHz
- Look angle ($\theta$): 22.8°
- Orbit incl. ($\alpha$): 12.9°
- Repeat cycle: 35 days
- Satellite altitude: 790 km
- Pixel spacing: 8m (slant range)
- Ground resolution: ~25-30 m
Satellite data processing

- Level 0 (raw) IM data
  - Range/Doppler sequence
  - SLCs
    - Radiometric calibration
    - Calibrated SLCs
      - Multi-looking
        - Resampled SLCs & MLIs
          - Co-registration
            - Resampled MLIs
              - Spatio-Temporal analysis of the data
                - Geocoding
                  - Derived products
                    - Refined lookup table
                      - GTC MLIs
                        - Derived products
                          - Geocoding
                            - GTC derived products

ASTER GDEM

- Master
  - Slaves
    - ASTER GDEM V2
      - Resampled MLIs
        - GTC MLIs & Derived products (map geometry)
Radar signatures

\[ \sigma^0 \text{ [2003-2005]} \]

Average backscattering coefficient

\[ \sigma^0[2003-2005] \]

Normalized temporal variability

\[ \bar{\sigma}_i^0 = \frac{1}{n} \sum_{t=t_1}^{t_n} \sigma_i^0(t) \]

\[ \sigma_i^0 = f(\lambda, \text{pol.}, \theta, \text{roughness}, \text{shape}, \text{dielectric properties}) \]

Groundwater fluctuations and cropland changes along river plains

Alterations of local morphology due to mass movements
River courses and urban areas have higher $\sigma^0$ than agricultural fields, dry and smooth surfaces (airport runaway and water bodies, e.g. *pozo cocha*).

Signal penetration depths are higher over the sand dunes of the Cerro Blanco, and $\sigma^0$ is lower than over the surrounding mountain regions.
Radar signatures

RGB ASTER [2003]  
NIR-Red-Green

σ₀ [2003-2005]
Temporal variations

- Comparison of temporal variability of radar returns from different surfaces
- Temporal history of average $\sigma^0$ within different AOIs

\[ \sigma^0_{AOI}(t) = \frac{1}{N} \sum_{i=1}^{N} \sigma^0_i(t) \]

\( t = \text{acquisition time} \)
\( N = \text{no. pixels within AOI} \)
\( i = i^{th} \text{ pixel} \)

Agricultural fields have different backscattering properties but similar temporal variations, hence are likely to follow groundwater fluctuations over the different seasons
Change detection

$15/11/2005$

$04/02/2003$

$3 \times 3$ or $5 \times 5$ spatial filtering

Ratio

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

$0 < R < 1$ if $\sigma_i^0(t_j) > \sigma_i^0(t_k)$

$R > 1$ if $\sigma_i^0(t_j) < \sigma_i^0(t_k)$
2004-2005: decreased $\sigma^0$ along the Rio Ingenio plain, except P1-P3 (ratio over 4-5)

May-Nov2005: decreased soil moisture over vegetated/agricultural areas

May2003 vs. Jun2004 (ASTER): decreased vegetation cover and soil moisture
Hydraulic networks

Ancient *puquios* in the Taruga valley

SAR colour composite

ASTER-derived NDVI

Ancient *puquios* in the Taruga valley
Mass movements

Wind/rain-driven morphological changes and mass movements cause local alterations of the backscattering coefficient
Landscape changes at regional scale

InSAR coherence cross-correlation between co-registered SLCs

Changes along river plains and over agricultural fields

Cahuachi

Wind/rain-driven mass movements

20041130_20050524
Bperp: 5 m
Btemp: 175 days
Landscape changes at local scale

**DESC mode**

- **20030204_20041130**
  - Bperp: 89 m
  - Btemp: 665 days
- **20041130_20050524**
  - Bperp: 5 m
  - Btemp: 175 days
- **20030204_20051115**
  - Bperp: 343 m
  - Btemp: 1015 days

**ASC mode**

- **20051002_20071007**
  - Bperp: 4 m
  - Btemp: 375 days
- **20071007_20071111**
  - Bperp: 180 m
  - Btemp: 35 days
From historical to recent landscape evolution

Oct. 2014

Baseline pre-defined mission observation scenario

- IW mode
- VV polarization
- 24 days repeat cycle per pass (asc./desc.) and alternating the passes asc./desc. (i.e. areas observed every 12 days.)
From historical to recent landscape evolution

S1 GRD IW VV
25th Oct. 2014
From historical to recent landscape evolution
From historical to recent landscape evolution
Conclusions & future research

- ERS-1/2 and ENVISAT C-band satellite radar data imaged the recent evolution of cultural landscape in Nasca since 1997
- SAR data proved capable to depict archaeological features, and to identify surface indicators of environmental changes in such a dynamic region
- Amplitude-based and coherence change detection reveal soil moisture and vegetation changes occurring along the river valleys
- Mass movements and other surface processes occur at seasonal and yearly scales across the Rio Grande catchment area
- Natural and anthropogenic factors expose the heritage of Nasca at risk
- Results with archive data show potential for environmental and archaeological studies with new Sentinel-1 imagery
- Future research will look at analysing the relationship between landscape evolution and climate change over the last 20+ years
REFERENCES


• TAPETE D., CIGNA F., MASINI N., LASAPONARA R. 2013. Prospection and monitoring of the archaeological heritage of Nasca, Peru, with ENVISAT ASAR. *Archaeological Prospection*, 20(2), 133-147.


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