The Emerging Role of Satellite and Aerial Remote Sensing in Managing Archaeological World Heritage Sites

Douglas C. Comer
President, ICOMOS/ICAHM, Governing Board Member, HIST

With special thanks to:
Bruce D. Chapman, JPL/NASA
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European Space Agency Conference
Advances in Remote Sensing for Cultural Heritage: from site detection, to documentation and risk monitoring
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Monitoring is Only the Beginning

Many programs are monitoring site disturbance/destruction (Syria, Iraq, Libya, Yemen, etc.)

- How do we use this information?
- Can we use it to determine causes, predict trajectories of disturbance, intervene?
Understanding the Problem

This is the first step

Obviously, satellite imagery can be informative

Models that draw up aerial and satellite imagery can be very useful (although this must be done carefully)
Extracting and Interpreting Data

Percentage of looted sites in IS areas not as high as in others, but percentage of heavily looted sites is much higher.

It is necessary then to develop programs, projects, and activities to solve the problem. First research and careful analysis, then management.

<table>
<thead>
<tr>
<th>Faction</th>
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* Analyzed sites are broken down according to areas of factional control as of early 2015 (SNAP 2015). Note that sites which straddle or are very close to approximate borders are counted in both regions.
Most of these geoglyphs were made by the people of the Nasca culture between the years 50 to 650 AD, although a small percentage were created by societies that date to earlier time periods, such as Paracas and Topará.

Area inside WHS: 450 km²
UVSAR
L-band HH, HV, VV (now has P-band pod)

UAVSAR Summary
Uninhabited Aerial Vehicle Synthetic Aperture Radar

Has collected thousands of flight lines of radar data since 2007 in the following fields of study:

- Earthquakes, Volcanoes, & other deformations
- Vegetation
- Ice & glaciers
- Soil moisture
- Oceanography
NASA UAVSAR Platform Deployments
a) Google Earth image © 2015 Digital Globe showing geometric geoglyphs. Yellow line indicates 100 m.  b) HH polarization image.  c) HV polarization image.  d) Color overlay of HH (red), HV (green), and VV (blue).
Produced by Bruce D. Chapman, JPL/NASA
Linear geoglyphs are distinguishable in the SAR imagery if they are characterized by a concentration of rocks along the path. Tire tracks and other types of paths that simply beat down the path are likely to be less discernable in the SAR imagery, but are just as easily visible in the optical imagery.
Black areas are those that have been disturbed between March 2013 and March 2015.

Clearly produced by flooding.

Severe rain events are forecast for 2016.
Hummingbird Geoglyph

100 m
Five indications of disturbance are observed:
1) a path from the unpaved road to the North;
2) an area as one enters the pampa from below, where an online video (https://www.youtube.com/watch?v=RzavtWbjXow) shows that equipment and people congregated
3) the area near the hummingbird geoglyph, in close approximation to where the Greenpeace banners were placed;
4) decorrelation within the head of the hummingbird itself; and
5) ridgeline areas of decorrelation where the slope is large and natural erosion may be occurring.
Dirt Roads and Power Lines,
Disturbance in Last Two Years

(indicated by black areas)
Putting Monitoring to Use

• 1. Identification and evaluation of extent of damage produced by the installation of the Greenpeace message in December of 2014.

• 2. Identification of risk areas and recommendations for risk reduction.

• 3. A structural catalogue of geoglyphs (statistical clustering of backscatter).

Black corresponds to decorrelation, typically due to disturbance between the two observations (March 2013 – March 2015), while grey and light grey correspond to areas with minimal decorrelation.
World Heritage Sites Exist in a Landscape

• Since the ratification of the World Heritage Convention in 1972, we have learned that most threats stem from changes on the landscape.

• Aerial and satellite technologies permit us to detect and understand these...
Petra

- Development upslope produces flooding in the World Heritage Site
Fields near Beidha, probably Nabataean, still intact. Still used by bedouin.

DEM developed from ASTER, courtesy Michael Abrams, JPL/NASA
Nabataean Fields

These reconstructions show the irrigation methods used by the Nabataean. The terraced wadi (3a) is still used by the bedouin. Remains of the runoff farm can still be found throughout the Negeb. The example shown is based on one discovered in the vicinity of Avedat.
Construction in the town of Wadi Musa, upslope from Petra, has obliterated the fields
Without buffering of fields, flooding

DEM developed from ASTER, courtesy Michael Abrams, JPL/NASA
At Orheiul Vechi, in Moldova, a site nominated to the World Heritage List, we used Lidar obtained for a hydrological study to detect heretofore unknown archaeological sites.

Iron Age Ring Fort Overlooking the Răut River
Orheiul Vechi, Moldova
Hillshade model derived from 30 cm resolution LIDAR data
But how do we make use of such detected features?

We can see several forts that are probably similar to Iron Age Ring Forts, like this one, Dun Aengus, in Ireland, first constructed 1100 BC.
Another Promontory Fort, Two Rings
More or Less Visible Depending Upon Enhancements

Many were Found

Lidar can be merged with multi-spectral
Using Site Detection

There are obvious research applications. However, a site can't be said to have been discovered until we know what the site is, and that required examination on the ground.

We can, however, use the distribution of sites that we detect in aerial and satellite imagery to establish boundaries within which the sites can be protected.
Archaeological Sites of the Island of Meroe

Heartland of the Kingdom of Kush, a major power from the 8th century B.C. to the 4th century A.D.

Empire extended from the Mediterranean to the heart of Africa

Inscribed on World Heritage List in 2011
Meroe (Begraweya)

- Capital during second Kushite golden age
- Wealth from iron production
- Pyramids and
- Town Site
Image on right shows sources of iron ore. Band ratio protocols developed by Ronald G. Blom, JPL/NASA, were used to highlight ferric and ferrous materials.
How Do Monuments Operate?

- The importance of viewshed
- The importance of maintaining viewshed
- Encroachment now can be monitored with access to the Internet
Remote Sensing Datasets

UAVSAR
Worldview 2
Landsat8

Data preparation (atmospheric correction, orientation area and pixel size)

Algorithm: Linear Discriminant Analysis (LDA)

Generating band-difference ratios to normalize data

Sampling random known non-sites (KNS) outside buffer

Previously known identified sites (KS)

Sampling technique

Validation, correcting data sets/ change of parameters

Field verification

Direct Detection Model (DDM)

QGIS

Matlab

ArcGIS
SRTM: 90m
UAVSAR: 5.8m

Landsat8: 30m (Pan 15m)
Worldview2: 2m (Pan 0.6m)

Aster: 30m (Pan 13m)
Aerial (RGB, only Haiti): 0.3m

Digital Detection Model
Current issues:
- pinpointing location of sites
- not full area surveys of non-sites
- Use of different RS data sets

Direct Detection Model (DDM)
Direct Detection Model (DDM)
Receiver Operating Characteristic (ROC) curve analysis of contribution of features

Direct Detection Model (DDM)
Summary

• The benefit of enhancing, analyzing, and interpreting aerial and satellite imagery lies in how what is extracted can be modeled.
• Modeling can be done for research purposes.
• Equally important is that it can be done to inform policies, programs, projects, and activities for the preservation and presentation of archaeological sites.

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