Archaeological Landscapes and Built Heritage: Climate Risk and Contribution of Remote Sensing Technologies

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Abstract The focus of this chapter is the contribution of remote sensing (RS) technologies in climate risk mainly for archaeological landscapes and built heritage. It will study the use of RS technologies for sea level rise scenario risk assessment and the use of multi-temporal multisource data and statistical indices for the detection of changes in built heritage. This chapter is divided in two sections: the first one focuses on sea level rise and potential threats, while the second one focuses on monitoring of temporal changes in built heritage using multisource multi-temporal data and indices.

Keywords Remote sensing · Sea level rise · Built heritage · Change detection · DEM production · UAV

Introduction

The focus of this chapter is the contribution of remote sensing (RS) technologies in climate risk mainly for archaeological landscapes and built heritage. Global climate changes due to various factors are causing risk not only to human life but also to cultural heritage. One of the most significant consequences of climate change is sea level rise. Sea level rise due to climatic change is evolving during the last decades

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posing a threat to all costal sites. A large number of cultural and natural heritage sites are either underwater or coastal at the moment. A search at the UNESCO World Heritage Center site (http://whc.unesco.org/en/list/) returned a total of 110 coastal or underwater heritage sites out of a total of 1073 sites, representing roughly 10% (September 2017). On the other hand, climatic changes have an effect in built heritage. In order to be able to monitor changes in built environments either historical city centers or settlements, the use of multi-temporal and multisource data is almost mandatory. The new remote sensing satellites coupled with historical maps and aerial photographs can provide a very powerful tool for the detection of such changes. Another effective methodology to monitor and document these changes is by using indices in order to study certain features and characteristics. This chapter is divided in two sections: the first one focuses on sea level rise and potential threats, while the second one focuses on monitoring of temporal changes in built heritage using multisource multi-temporal data and indices. Each section is complemented with the presentation of implemented case studies. For the first section "Sea Level Rise and Potential Threats to Heritage," a case study presenting the use of remote sensing satellite data and UAV imagery for the production of DEMs and orthoimages is presented. For the second section "Monitoring of Temporal Changes in Built Heritage Through Indices," two case studies are presented. The first one presents the identification of changes in the historic center of Nicosia using multisource and multi-temporal data, while the second one examines the changes that occurred in the settlement of New Mesibria using statistical indices applied to aerial photographs.

Sea Level Rise and Potential Threats to Heritage

This section focuses on methodologies and tools that deal with sea level rise (SLR) potential threats to underwater and heritage sites. According to (UNESCO 2007), SLR will threaten the coastal area with coastal erosion and permanent submersion of low-lying areas along with an increase in sea-salt chloride load in the coastal soils. Recent projections of SLR are predicting an increase of approximately 1 m in sea level globally based on different types of scenario (Carson et al. 2016; Kopp et al. 2014; Jorda 2014). In order to assess the impacts of SLR to coastal areas, most of the studies (SLR scenarios) can be divided in two categories: (a) aggregation of global exposure surveys that can quantify the impact and (b) high-resolution site-specific studies that target specific areas and their results cannot be extrapolated to predict global estimates with respect to coastal impact (Diaz 2016). Different studies regarding SLR scenarios have been performed in the recent years. (Anzidei et al. 2017) performed a flooding scenario for the Lipari Island in Italy. Their study revealed that an area of 12,500 m^2 or 17,500 m^2 is going to be flooded by 2100 AD in a coastal strip of about 700 based on a 1.36 m and 1.60 m potential SLR scenario, respectively. Wardell-Johnson et al. (2015) performed a study for the K'gari-Fraser Island. They concluded that although K'gari-Fraser Island is unlikely to experience coastal flooding due to SLR over the next century, even small rises could result in saline contamination of low-lying areas of the island. (Marzeion and Levermann 2014) performed a study focused on loss of cultural word heritage due to SLR. In their study, they used a global DEM (SRTM and ETOPO1) to run a scenario and predict coastal flooding over the next two millennia. Their study predicted that out of the 720 sites listed in UNESCO World Heritage List in October 2012, 136 sites will be impacted by SLR if a warming of $\Delta T = 3$ K is sustained over the next two millennia.

In order to be able to assess potential threats and run SLR scenarios, a detailed (high resolution) and accurate DEM of the region is required. The technological advancements along with the new very high-resolution satellites provide the answer for fast and accurate 3D modeling. In this chapter, the methods and resources that can be used to provide accurate mapping are going to be presented. Remote sensing data or global DEMs derived from satellites can help to predict vulnerable areas globally.

Cultural Heritage Mapping with Remote Sensing

For SLR disaster assessment, the costal line and the area's DEM are enough in order to create risk assessment maps. Depending on the SLR scenario, short- or long-term one must choose the proper resolution and accuracy of the DEM. Remote sensing is widely used for mapping large areas. The new satellites provide very high-resolution data down to 0.30 m pixel size, thus being able to map heritage sites, and create high-resolution DEMs. In the following table, an indicative list of high and very high satellite data that can be used for the production of DEMs suitable for risk assessment with respect to SLR and costal disasters is presented.

In Table 1, the current satellites with a resolution of 2.5 m or better are presented. Other satellite data can be also used for the temporal and historical monitoring of heritage sites. The Landsat mission can provide a very thorough source of data for temporal analysis. Another source of potential historical data which can provide satellite photos of high resolution but with limited global coverage is the declassified intelligence satellite photographs (DISP). Their resolution ranges from 1 to 140 m and was part of the CORONA, ARGON, LANYARD, GAMBIT, and HEXAGON satellite programs (USGS 2008). Detailed information about the DISP archive can be found in (Fowler 2013).

Existing global DEMs can be used to produce SLR risk assessment maps in small scales but for covering larger areas. The following table presents and indicates list of existing free/proprietary global or regional DEMs.

The Shuttle Radar Topography Mission (SRTM) used two SARs, a C band system (5.6 cm, C radar) and an X band system (3.1 cm, X radar) (Farr et al. 2007). SRTM collected radar data over 80% of the Earth's land surface between 60° north and 56° south latitude with data points posted every 1 arc-second (approximately 30 meters) (https://lta.cr.usgs.gov/SRTM). The accuracy of the SRTM data was assessed by Rodriguez et al. (2005) (Table 2).

Table 1 Current 2.5 m and better resolution land imaging satellites (Stoney 2007)

Satellite		Country	Launch date	Panchromatic resolution (m)	Multispectral resolution (m)
1	WorldView-3	USA	08/13/14	0.3	1.2
2	WorldView-4	USA	11/11/16	0.3	1.2
3	GeoEye-1	USA	03/16/07	0.4	1.6
4	WorldView-1	USA	07/01/07	0.5	
5	WorldView-2	USA	07/01/08	0.5	1.8
6	Quickbird-2	USA	10/18/01	0.6	2.4
7	Gaofen 2	China	08/19/14	0.8	3.2
8	Pleiades-1	France	03/01/09	0.5	2.0
9	Pleiades-2	France	09/01/10	0.5	2.0
10	KOMPSAT 3	Korea	05/17/12	0.7	2.8
11	KOMPSAT 3A	Korea	03/25/15	0.5	2.2
12	EROS B1	Israel	04/25/06	0.7	
13	EROS C	Israel	03/21/08	0.7	2.5
14	TripleSat	India	07/10/15	0.8	3.2
15	SkySat 1	USA	11/21/13	0.9	2.0
16	SkySat 2	USA	7/8/14	1.1	2.0
17	TanDem-X	Germany	06/30/09	1.0	
18	TerraSAR-L	Germany	08/15/08	1.0	
19	TerraSAR-X	Germany	10/31/06	1.0	
20	IRS Cartosat 2	India	03/15/07	1.0	
21	COSMO-Skymed-1	Italy	11/12/07	1.0	
22	COSMO-Skymed-2	Italy	05/01/08	1.0	
23	COSMO-Skymed-3	Italy	11/01/08	1.0	
24	COSMO-Skymed-4	Italy	05/01/09	1.0	
25	Arirang-2 (KOMPSAT-2)	Korea	07/28/06	1.0	4.0
26	Resurs DK-1 (01-N5)	Russia	06/15/06	1.0	3.0
27	IKONOS-2	USA	09/24/99	1.0	4.0
28	OrbView 3	USA	06/26/03	1.0	4.0
29	SPOT 6	France	09/09/12	1.5	6.0
30	SPOT 7	France	06/30/14	1.5	6.0
31	EROS A1	Israel	12/05/00	1.8	
32	FormoSat (RocSat 2)	Taiwan	04/20/04	2.0	8.0
33	TH 01	China	2010,12,15	2.0	10.0
34	THOES	Thailand	06/30/07	2.0	15.0
35	Alsat-2A	Algeria	12/01/08	2.5	10.0
36	Alsat-2B	Algeria	12/01/09	2.5	10.0
37	SPOT-5	France	05/04/02	2.5	10.0
38	IRS Cartosat 1	India	05/04/05	2.5	
39	ALOS	Japan	01/24/06	2.5	10.0
40	CARTOSAT-1	India	05/05/05	2.5	
41	RazakSat	Malaysia	11/01/06	2.5	5.0
42	Spain Sat	Spain	07/01/10	2.5	
43	TopSat (SSTL)	UK	10/27/05	2.5	5.0

Table 2 Free global or regional DEMs

Dem	Grid (m)	Positional accuracy (m)	Vertical accuracy (m)	Free or proprietary
SRTM	30 × 30	8.8–12.6	5.6–9	Free
ASTER GDEM	30 × 30	18–20	15–17	Free
DLR SRT	25 × 25	20	16	Free
EU-DEM	25 × 25	<5	2.9	Free
ALOS world 3D 30	30 × 30	<10	5	Free
ALOS World 3D	5 × 5	<5	5	Proprietary
Elevation 30	30 × 30		8	Proprietary
Elevation 8	8 × 8		3	Proprietary
WorldDEM (TerraSAR-X and TanDEM- X)	12 × 12		4	Proprietary
Elevation 4	4 × 4		2	Proprietary
Elevation 1	1 × 1		1.5	Proprietary

The ASTER Global Digital Elevation Model Version 2 (GDEM V2) was jointly released on October 17, 2011, by the Ministry of Economy, Trade, and Industry (METI) of Japan and the US National Aeronautics and Space (NASA). Its coverage spans from 83 degrees north latitude to 83 degrees south, encompassing 99 percent of Earth's landmass. (Tachikawa et al. 2011) published a report that validated the ASTER GDEM v2 results. According to their study, the ASTER GDEM v2 demonstrates a positional accuracy of approximately 18–20 m and an absolute vertical accuracy of approximately 15–17 m.

The X band radar measurements of SRTM were processed by DLR creating a global DEM with a grid size of approximately 25 × 25 meters.

The ALOS world DEM was generated by the Japan Aerospace Exploration Agency (JAXA). The DEM was generated using the archived data of the Panchromatic Remote sensing instrument (PRISM) on board the Advanced Land Observing Satellite (ALOS). ALOS operated from 2006 to 2011 acquiring approximately 6.5 million scenes covering the entire globe (Tadono et al. 2014). PRISM was an optical sensor consisting of 3 radiometers for Nadir, forward and backward looking with a 2.5 m spatial resolution and 35 km swath width.

The ALOS world 3D 30 m mesh was produced by the ALOS world 3D. The ALOS world 3D is a fine resolution DEM with a grid size of 5 m covering the +/− 80 degrees latitude regions. The ALOS World 3D 30 m DEM was generated by resampling 7 × 7 pixels on the AW3D DEM dataset (Tadono et al. 2016). Tadono et al. (2016) evaluated the achieved accuracies of the AW3D30DEM and concluded that it can provide a height RMSE of 4.4 m.

The EU-DEM was generated based on SRTM, ASTER GDEM, and public available Russian Maps. It provides Pan European elevation data with a grid of 25 meters. Based on the validation of Tottrup (2014), the EU-DEM has an overall vertical accuracy of 2.9 m RMSE and a horizontal accuracy better than 5 m.

In addition, several licensed global or regional DEMs exist. One of the major distributors of medium- to very high-resolution DEM data is Airbus (http://www.intelligence-airbusds.com/en/66-geo-elevation-and-dem). Elevation 30, 8, 4, and 1 and the WORLDDEM are distributed by them. Their DEMs are produced either by optical satellites (SPOT 5/6, Pleiades) or radar (TerraSAR-X, TanDEM-X). Global DEMs can be used to assess potential threats when examining long- or medium-term sea level rise scenarios. When one needs to assess potential short-term sea level rise threats in a small area, then aerial or UAV imagery can be used for DEM production. UAV imagery can achieve ultrahigh-resolution DEM reaching 2–4 cm with an accuracy of 1–2 cm.

Lefkas Case Study

In order to demonstrate the use of remote sensing and UAVs in the production of 3D models of heritage sites, a case study performed in the Lefkas island is presented. Two different regions were mapped: one in the north part and one in the south part of the island. The north part of the island includes a part of the city of Lefkas and the adjoining lagoon, while the south part is a mapping of the coastal town of Vassiliki. Two different approaches were demonstrated for the production of high-resolution DEMs and orthoimages. The first approach was based on satellite imagery (WorldView-1 and WorldView-3) and the second one on UAV image acquisition.

Remote Sensing Mapping

In this section, the study case regarding the production of DEM and orthoimages for the two areas of the Lefkas island using WorldView-1 and WorldView-3,satellite imagery is going to be presented. Two different WorldView stereopairs were acquired, one for each area.

For the north area covering part of the Lefkas city and the adjoining lagoon, two WorldView-1 panchromatic images, with 0.50 m resolution and acquisition date 11 April 2017, were acquired. In addition, a multispectral WorldView-3 image with 0.30 m panchromatic resolution and 1.2 m MS resolution with acquisition date 16 April 2009 was acquired. A total of 26 ground points (16 used as ground control points and 10 as check points) were measured using GNSS RTK with a 0.05 m accuracy and used for the processing of the images (Fig. 1).

The triangulation yielded an accuracy of 0.31 m in *X*, 0.39 m in *Y*, and 0.45 m in *Z*. Using the panchromatic stereopair, a DEM of the area was created with a grid of 2 × 2 m. The DEM production yielded the following results (Tables 3 and 4).

The orthoimage was produced using data fusion between the MS and the PAN image. The registration was performed using the DEM and GCPs and satellite resection. The total RMS error of the orthoimage was 1.26 pixel or 0.38 m.

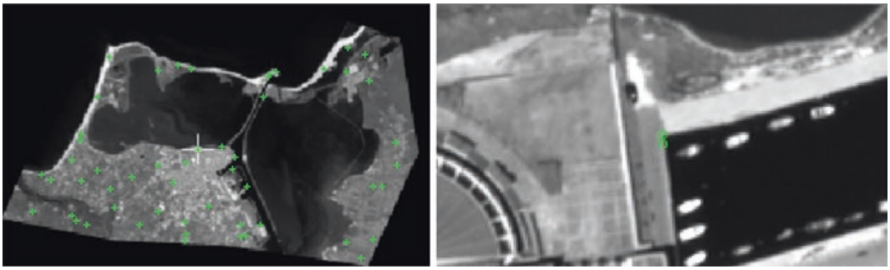

Fig. 1 Ground control points and check point distribution (left) and control point detail. (WorldView 1© 2017DigitalGlobe, Inc)

Table 3 North area DEM accuracy information: general mass point quality

DEM (2 × 2 m)		
Excellent	74.13%	
Good	14.00%	
Fair	0.000%	
Isolated	0.000%	
Suspicious	11.87%	

Table 4 North area vertical accuracy

Total # of 3D reference points used	10
Min, max error	−2.52, 0.75
Mean error	−0.77
Mean absolute error	0.96
(RMSE)	1.21
LE90	1.59

Table 5 South area DEM accuracy information: general mass point quality

DEM (2 × 2 m)		
Excellent	74.47%	
Good	14.61%	
Fair	0.000%	
Isolated	0.000%	
Suspicious	8.92%	

For the second area, a WorldView-3 stereopair (PAN-MS) with a resolution 0.30 m PAN, and 1.20 m MS acquired on 28 December 2015, was used. A total of 27 ground points (17 used as ground control points and 10 as check points) were measured using GNSS RTK with a 0.05 m accuracy and used for the processing of the images. The triangulation yielded an accuracy of 0.12 m in *X*, 0.15 m in *Y*, and 0.29 m in *Z*. The produced 2 × 2 grid DEM yielded the following results (Tables 5 and 6).

The total RMS of the produced orthoimage was 0.86 pixel or 0.26 m. Figure 2 presents the produced orthoimages.

Table 6 South area vertical accuracy

Total # of 3D reference points used	10
Min, max error	−1.83, 0.56
Mean error	−0.24
Mean absolute error	0.54
(RMSE)	0.72
LE90	0.67

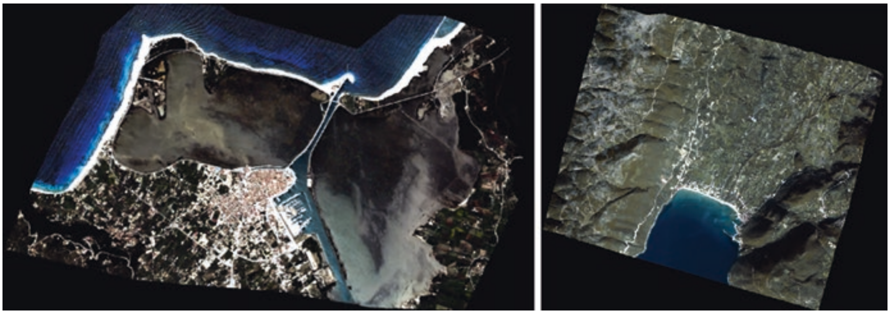

Fig. 2 The produced orthoimages (Lefkas city left, Vassiliki right). (WorldView 1© 2015 Digital Globe, Inc)

UAV Mapping

The UAV mapping was performed using an eBee fixed-wing UAV equipped with the 1 inch 20 megapixel SODA sensor. The filed surveys were realized in May–June 2017. A total of 2702 images were used for the DEM and orthoimage production for the north area, while a total of 1056 images were used for the south area. Ground control points were measured using GNSS RTK with an accuracy of 0.02 m. 37 control points and 6 check points were used for the photogrammetric processing of the north area, and 20 control points and 5 check points were used for the south area. The results provided a check points RMSE of 0.03 m, 0.04 m, and 0.03 m in the *X*, *Y*, and *Z* axes, respectively, for the north area and 0.03 m, 0.01 m, and 0.04 m for the south area. The final DEM was produced with 0.04 × 0.04 m grid and the orthoimages produced with a pixel size of 0.04 m (Fig. 3).

Conclusion

SLR is an effect of the climatic change that can potentially threat cultural heritage. Global sea level rise scenarios predict a rise in the sea level of approximately 1–1.2 m for the next 100 years. Furthermore, area-specific SLR scenarios predict rises up to 5–7 mm/year. In order to be able to assess potential threats (flooding, coastal erosion, etc.) to cultural heritage, the area's topography, namely, the DEM

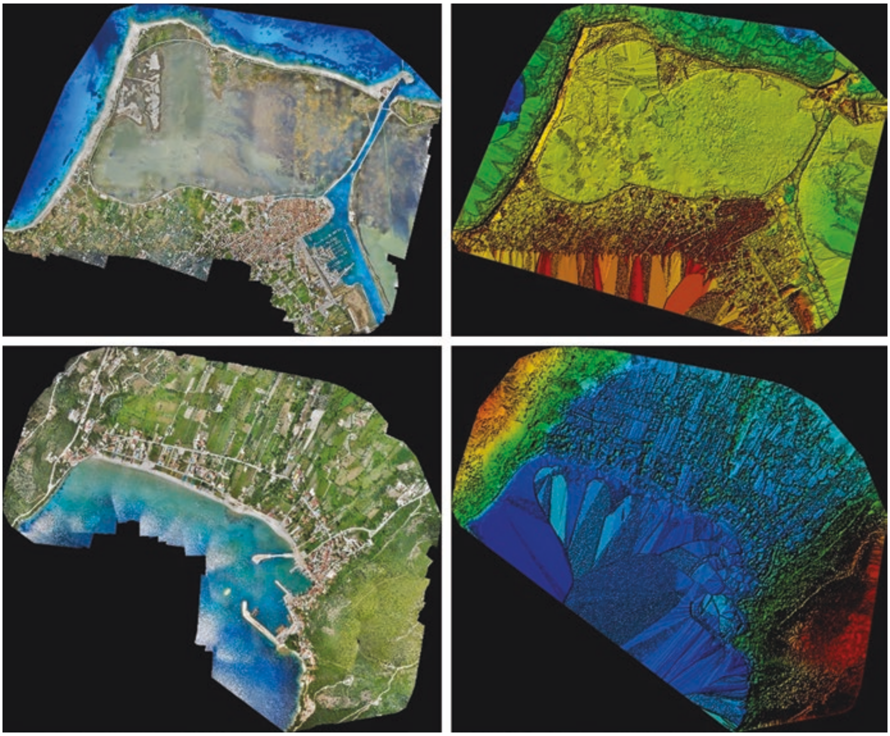

Fig. 3 The UAV imagery produced orthoimages and DEMs (the north area, top; the south area, bottom)

and the coastline, should be known. For very long-, long-, and medium-term SLR scenarios, very high-, high-, or medium-resolution and very high-, high-, and medium-accuracy DEMs are adequate for the assessment of potential threats. For short-term scenarios, ultrahigh-resolution and ultrahigh-accuracy DEMs are needed. Global DEMs, either free or proprietary, produced by remote sensing satellites, can be used for the assessment of risk in very long-, long-, and medium-term SLR scenarios. High- and very high-resolution satellite images can be used for the production of DEMs for the assessment of SLR risks in long- and medium-term scenarios because they can provide the adequate resolution and accuracy. Free global DEMs have a grid resolution of either 25 m or 30 m, while their horizontal and vertical accuracy span between 5 and 20 m and 3–17 m, respectively. Finally ultrahigh-resolution DEMs produced by UAV imagery can help assess SLR threats for short-term scenarios as they can provide resolution down to 2 cm with an accuracy of 1–2 cm. Furthermore, a case study demonstrating the results that can be achieved in DEM production using VHR satellite data and UAV was presented. VHR satellite images processing can achieve DEM production with an accuracy of 0.3–0.4 m horizontally and 0.5–1.0 m vertically, while UAV imagery can achieve DEM production with an accuracy of 0.01–0.02 m horizontally and 0.02–0.04 vertically creating DEMS with a resolution of 0.04 m.