Archaeological lidar in Greece: a summary of recent work

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Introduction

Aerial lidar data have had a dramatic effect on the study of archaeological landscapes. Discoveries of whole cities or previously unknown regional systems of settlement in the Maya Lowlands, the Amazon, and the jungles of southeast Asia have made headlines and gripped the popular imagination, as in well-known examples from Caracol in Belize or Angkor Wat in Cambodia.[1] Mediterranean applications have received less acclaim, but are no less significant for understanding past landscapes.[2] High-resolution elevation models and the unique ability of lidar to 'see' beneath vegetation offer archaeologists the opportunity to detect and map subtle variations in the landscape and features that may otherwise go unnoticed, often over large areas.

In what follows, I provide some introduction to lidar-based archaeological research, a summary of published and ongoing work in Greece, and some key considerations for how this work may fit into wider dialogues concerning archaeological remote sensing as we move forward. Many of these topics are relevant for survey archaeologists working elsewhere as well. I argue that lidar holds tremendous potential for archaeological research in Greece, especially at a regional scale. Several innovative projects are well underway, but collective research agendas remain nascent. Archaeologists now have a crucial opportunity to work toward certain shared goals and deploy a common set of standards for good practice, related to methodological transparency and the generation of accessible and comparable datasets, both in publication and in archival practices.

Lidar in archaeology

Lidar has been used for aerial mapping since the 1970s, with archaeological applications since the 1990s.[3] Globally, we have witnessed a resounding boom in the last 20 years as the use of lidar became more widespread and accessible to more researchers, especially in archaeology. Recent review articles have highlighted promises and challenges of the technology, as well as its global distribution, which remains quite uneven.[4] The most basic use of lidar data is for the identification and mapping of archaeological sites and features. Several unique features of lidar – its precision, its scalability, and its capacity to penetrate vegetation cover – make it particularly well-suited for archaeological research and adaptable to a wide variety of environmental circumstances.

I provide a brief summary of the workflow. Aerial lidar, also known as aerial laser scanning (ALS) normally involves a planned flight to cover a study area with a series of parallel and overlapping strips. During the flight, a sensor produces millions of laser pulses whose reflected distance to ground (or other objects) can be measured precisely, providing a point cloud for anything in the path of the sensor (buildings, powerlines, vegetation, cars, animals, and the ground). The vertical resolution

[1] Chase *et al.* 2011; Evans *et al.* 2013.
[2] E.g., in Lebanon: Rom *et al.* 2020; at Kolophon in Turkey: Grammer *et al.* 2017; in Spain: Belarte *et al.* 2019; and in southern Italy: Masini *et al.* 2018. See also discussion in Attema *et al.* 2020: 30-33; Knodell *et al.* 2023: 301-302.
[3] Opitz 2013.
[4] Inomata 2024; Vinci *et al.* 2025.

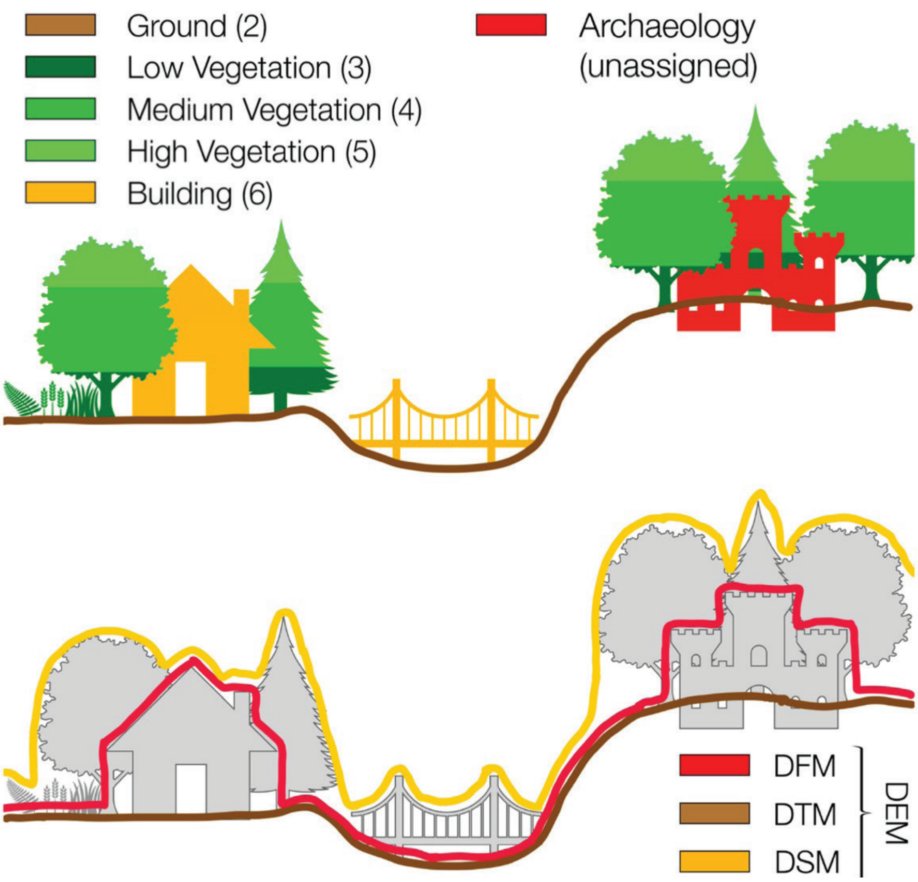

Figure 1. A common schema for the classification of point cloud data, showing also what is included in DSM, DTM, and DFM representations of lidar data (Štular *et al.* 2021b: Figure 1, published open access and reproduced under CC-BY 4.0).

is such that even subtle elevation differences caused by drainage episodes, goat trails, or plowing a field can be detected. After the initial data collection, point cloud files are classified according to what each point represents and then interpolated to create Digital Surface Models (including all classifications) and Digital Terrain Models (a 'bare earth' model with vegetation removed) (Figure 1). One issue is that sometimes archaeologically interesting features are removed along with the vegetation, necessitating the use of multiple visualizations, including high-resolution aerial photos. We can also reclassify the data manually to create a Digital Feature Model, or DFM, that removes only vegetation and keeps walls, buildings, and other cultural phenomena intact. DSMs, DTMs, and DFMs can then be used to generate derivative products in the Relief Visualization Toolkit.[5] These visualizations highlight different types of features in different ways, and it is well established that a variety of visualizations are most useful in interpreting archaeological topography.[6]

Data acquisition classification, and the generation of different types of Digital Elevation Model (the DSM, DTM, and DFM) are only the first steps, however (Figure 2). These raster datasets are then used to create different types of derivative products, or visualizations, that can be used for interpreting archaeological landscapes, vectorizing features, and more. For example, the Red Relief Image Map (RRIM) highlights unusually convex and concave features in the landscape, which can often be a sign that they are human made.[7] In Greek contexts, the Red Relief image map is particularly adept at detecting terraces, other landscape modifications, and buildings. Several of the papers in this

5 Zakšek *et al.* 2011; Kokalj and Somrak 2019; Lozić and Štular 2021; Štular *et al.* 2021a.
6 Canuto *et al.* 2018; Kokalj and Somrak 2019.
7 Chiba *et al.* 2008; Inomata *et al.* 2017.

	Phase	Step	Workflow Step	Arch. Engagement
1	Raw data acquisition & Processing	1.1	Project planning	+
		1.2	System calibration	o
		1.3	Data acquisition	o
		1.4	Registering	+
		1.5	Strip adjustment	o
2	Point cloud processing & Derivation of products	2.1	Automatic ground point classification	++
		2.2	Object-type classification	++
		2.3	Manual reclassification	+++
		2.4	DFM interpolation	+
		2.5	Enhanced visualization	+++
3	Archaeological interpretation	3.1	Data integration	++
		3.2	Interpretative mapping	+++
		3.3	Ground assessment	+++
		3.4	'Deep' interpretation	+++
		3.5	Automated mapping	++
4	Dissemination & Archiving	4.1	Data management	+
		4.2	Dissemination	+
		4.3	Archiving	+

Figure 2. Model of data collection and workflow for archaeological lidar analysis (table 2 in Lozić and Štular 2021: table 2, published open access and reproduced under CC-BY 4.0).

collection make use of this visualization technique, among others, in order highlight different types of archaeological features in Greek landscapes. A natural next step is the identification and classification of features and areas of interest, in line and polygon vectors, from which we can assign and then analyze qualitative and quantitative information.

Vinci and colleagues recently published a systematic review of lidar applications in archaeology in the journal *Archaeological Prospection*, as part of a special issue on lidar in archaeology more broadly.[8] This article provides a wealth of information for researchers interested in archaeological lidar, some of which is worth highlighting here. First, the authors show a clear increase in the number of papers published in international archaeology journals over the last twenty years. The review is based on a dataset of 291 case studies, of which 167 are located in Europe, 104 in the Americas, and only 20 elsewhere. It should be noted that, while this method of review is systematic, it is not comprehensive, and there are many examples of other projects published in regional journals, books, and scientific literature in languages other than English. For example, this review did not include articles and case studies in what was previously the most comprehensive treatment of the issue, a collection of essays edited by Opitz and Cowley.[9] Nor does it include the recent publication in this journal of work at Aphidna.[10] Nevertheless, the shared parameter of international journals provides an axis for comparison. Some trends are immediately clear. First, most case studies are located in countries that have either open or partially open lidar data (Italy, the UK, Spain, and the US had the most numerous case studies and all have open lidar data).[11] Second, heavily forested areas with long histories of archaeological research have high concentrations of lidar projects, the most prominent examples being dense rainforests of the Yucatan Peninsula of Central America and Cambodia in southeast Asia. In Europe there are heavy concentrations of projects in the UK, Spain, Italy, and Croatia. While several projects have occurred in Mediterranean countries, the authors ask '...why is lidar so poorly applied in the Mediterranean region?'[12] While I do not agree with this phrasing, it is true that Mediterranean applications are less widespread and systematically applied than in some other zones. And many countries have seen little or no lidar work. Only one project

[8] Vinci *et al.* 2025.
[9] Opitz and Cowley 2013.
[10] Agapiou *et al.* 2022.
[11] Vinci *et al.* 2025: 89-94.
[12] Vinci *et al.* 2025: 83.

from Greece appears in this review, and only as a dot on a map.[13] There is also notably little lidar work in other areas of particular archaeological significance, such as North Africa and the wider eastern Mediterranean.

Despite its lack of historical representation, lidar is on the rise in Mediterranean archaeology. The importance of lidar for archaeological prospection was highlighted in two recent reviews of archaeological survey in the Mediterranean. In a recent article in this journal, Attema and colleagues noted examples from several areas, mostly where lidar was freely available.[14] Later, some colleagues and I highlighted the growing importance of lidar for regional-scale analysis, especially in areas where data are openly or widely available.[15] Unfortunately, Greece is not a country with open lidar, meaning data have to be acquired either independently (by an archaeological project, for example, with permission of the Ministry of Culture) or commercially (from a private vendor, again with proper permissions for any archaeological use). All of this should be seen in light of broader developments that involve the integration of remote sensing, spatial analysis, and other digital methods in archaeological surveys, which constitute a relatively new paradigm for regional archaeology,[16] following the 'new wave' of intensive survey projects of the late 1970s to 1990s.[17]

Published lidar studies in Greece

While only a few lidar studies in Greece have been published, results are already impressive (Figure 3). I note here that I focus on aerially acquired lidar data (ALS), and I do not include examples of terrestrial lidar or mobile-device-based scans, though these have been used to create detailed topographic maps as well, for example at Methone in the north Aegean,[18] or during several ongoing archaeological projects making use of lidar scanners on iPhone Pro and iPad Pro mobile devices, first released in 2020.[19]

All of these early studies involved the aerial acquisition of lidar data over relatively small areas, under 30km^2. The scan from Itanos, carried out in 2004, had a point density of about 1 point per sq m, while the later missions had much higher resolution, with returns of 25–70 points per square meter. In each case, the data were used primarily for detecting linear features, which were more apparent in the lidar data than in other forms of remote sensing, chiefly aerial photographs or satellite images.

The Kotroni Archaeological Survey Project (KASP), which focuses on the site and environs of ancient Aphidna, was an early adopter of lidar technology in Greece. Here, analysts mapped over 25 km of linear features – primarily terraces – though other, more subtle features were also noted, using a combination of lidar and other remote sensing methods.[20] While the KASP team participated in the initial conference at the ASCSA, they were unfortunately not able to include a publication of their ongoing work in this volume.

Two recent projects in Boeotia have also deployed lidar analyses to productive ends, and revisit that work in this volume. At Akraiphia, a gridded town plan, previously undetectable, was discerned.[21] Work in the Valley of the Muses revealed new information about the sanctuary there, including new and previously unknown structures and enclosures beyond the long-known theatre,

[13] Rowlands and Sarris 2007.
[14] Attema *et al.* 2020: 30-33.
[15] Knodell *et al.* 2023: 301-302.
[16] E.g., Campana 2016; Knodell and Leppard 2018.
[17] Bintliff 1994; Cherry 1994; for a new overview of archaeological surveys in Greece see Knodell 2025.
[18] Morris *et al.* 2020: 675–676.
[19] Luetzenburg *et al.* 2021; Knodell *et al.* 2025
[20] Agapiou *et al.* 2022.
[21] Lucas and García Sánchez 2022; see also Lucas this volume.

Figure 3. Published archaeological lidar projects in Greece.

south stoa and great altar.[22] In Thessaly, a lidar survey of the ancient city of Melitaia was used alongside historical documentation by Habbo Lolling to better understand the topography and archaeological landscape.[23] In Epiros, a recent publication provides a set of open-source methods for a drone-based study of the site of Kastri-Pandosia.[24] Another case study for drone-based lidar focuses on the documentation of excavation trenches at the site of Paleokastro (Gizi Castle) on Mykonos.[25] Finally, a recent PhD dissertation by Christos Chountolesis focused on the automatic mapping of terraces using lidar and orthophotography on the island of Hydra.[26]

Ongoing projects

By the time these studies were published, several other projects involving lidar analysis had begun, including large-scale data acquisitions in central Euboea, the Kephissos Valley, and the Cyclades

[22] Lucas and García Sánchez 2022; Garcia Sánchez *et al.* this volume.
[23] Rönnlund 2024. See also Rönnlund this volume.
[24] Abate *et al.* 2025.
[25] Adamopoulos *et al.* 2023.
[26] Chountolesis 2022.

project name	date (mo.-year)	area (sq km)	method of acquisition	agency/ company	sensor(s)	flight height	mean point density (/sq m)	pixel resolution (present analysis)
Itanos	04-2004	10	Aerial	–	Optech ALTM 3033	–	1	1 m
Kephissos Valley Project	2018	145	Aerial	Geosystems Hellas	RIEGL VQ-1560i-DW RGB camera; LMS-Q680i laser scanner	–	50.6	0.25m
Kotroni Archaeological Project	06-2018	24	Aerial	AeroPhoto	Riegl LMS Q1560; Phase One IXA-180 orthocamera	–	35	0.25m
Diolkos	≤ 02-2019	2	Aerial	AeroPhoto	–	–	–	–
Paleokastro Hill, Mykonos	≤ 2021	–	UAV	–	Zenmuse L1 Livox Mid-70; DJI Matrice 300 RTK Drone; DJI D-RTK 2 sensor	30m	40,000	4mm
Akraiphia	05-2021	2.5	Aerial	AeroPhoto	RIEGL VQ1560II; PhaseOne iXU-RS 1000	–	86	0.25m
Eretria-Amarynthos Survey Project	05-2021	240	Aerial	AeroPhoto	RIEGL VQ1560II with integrated Applanix 610/ IMU-57 and PhaseOne iXU-RS 1000 50mm RGB 100MP camera	3100ft	33	0.25m
Valley of the Muses	05-2021	2	Aerial	AeroPhoto	RIEGL VQ1560II; PhaseOne iXU-RS 1000	–	97	0.25m
Aigeira	2021	1	Aerial	Geosystems Hellas	–	–	–	–
Small Cycladic Islands Project (plus other Cycladic islands)	04- 2022	84	Aerial	AeroPhoto	RIEGL VQ1560II with integrated Applanix 610/ IMU-57 and PhaseOne iXU-RS 1000 50mm RGB 100MP camera	3000ft (small islands) and 4500ft (larger islands)	34; 8	0.25m
Melitaia Archaeological Programme	10-2022	3.8	Aerial	Geomatics	RIEGL VQ1560II and Phase One	–	15–20	0.1m
Small Cycladic Islands Project (southern Cyclades)	03- 2023	12	Aerial	AeroPhoto	RIEGL VQ1560II with integrated Applanix 610/ IMU-57 and PhaseOne iXU-RS 1000 50mm RGB 100MP camera	3600ft	25	. 0.25m
Pentelikon Marble Quarries Lidar Survey	06-2023	2.4	UAV	self	RUSA Surveyor 32; DJI Matrice 600 Pro	60m	300+	0.25m
Samothrace Lidar Project	2023	107	Aerial	AeroPhoto	RIEGL VQ1560II-S with integrated Applanix 610/IMU-57 and PhaseOne iXU-RS 1000 50mm RGB 100MP camera	4500ft	21	0.25m
Naxos Quarry Project	02-2024	2	UAV	self	Zenmuse L1 Livox Mid-70; DJI Matrice 300 RTK Drone; Emlid Reach RS2 GNSS receiver	90m; 60m; 30m	635; 1765; 4530	1.58cm–2.54cm
Palaiokastro, Pylos	≤ 03-2024	0.05	UAV	self	3DT Scanfly LITE X; DJI Matrice 300 RTK Drone; Topcon Hiper HR GNSS receiver	60m	–	–

project name	date (mo.-year)	area (sq km)	method of acquisition	agency/ company	sensor(s)	flight height	mean point density (/sq m)	pixel resolution (present analysis)
Perachora Archaeological Project	05-2024	8.2	Aerial	AeroPhoto	RIEGL VQ1560II-S with integrated Applanix 610/IMU-57 and PhaseOne iXU-RS 1000 50mm RGB 100MP camera	4500ft	37	0.25m
Central Achaia Phthiotis Survey	≤ 2024	9	Aerial	–	–	–	–	–
Halos	06-2023	4.27	UAV	self	Zenmuse L1 Livox Mid-70; DJI Matrice 300 RTK Drone; GNSS RTK network by METRICA's HxGN SmartNet	50m; 160m	1000–1300; 700	1cm; 2.7cm
Kastri-Pandosia	≤ 2024	0.65	UAV	self	Riegl MiniVux-3 5-echo TOF laser scanner; GNSS PPK positioning system; DJI Matrice 600	70m	2000	0.25m

Figure 4. Table indicating describing basic parameters and conditions for lidar acquisitions discussed in this special issue.

(Figures 4-5). One feature of these newer projects was a desire to extend the coverage of the remote sensing data to cover whole landscapes or small regions, often alongside field surveys. Researchers working on these projects and others gathered in March of 2024, in order to share their work and discuss common methods, problems, and future prospects. [27]

Since the conference in 2024, a handful of additional projects have come to light, at varying stages of analysis and (usually preliminary) publication. The Central Achaia Phthiotis Survey has also deployed lidar, resulting in the discovery of several previously unknown Early Iron Age tholos tombs.[28] Another ongoing survey, of the peninsula of Perachora, recently introduced a program of lidar analysis.[29] Unmanned Aerial Vehicles (UAVs/drones) equipped with lidar scanners have also been used in Messenia at Palaiokastro, near Pylos, for archaeological and geoarchaeological documentation of sites and landscapes at relatively small scales (0.6ha).[30] There are almost certainly other examples of ongoing, lidar-based work in Greece that I am simply not aware of at the time of writing.

This special issue has the same broad scope of the original conference, and papers are organized around the following themes: lidar analysis in regional surveys; aerial lidar and the study of archaeological sites; UAV lidar surveys; and, finally, two papers that reflect on the wider Mediterranean context of this relatively new practice in Greece. Together, these papers highlight a wide variety of recent and ongoing work concerning archaeological lidar in Greece (Figure 5).

Lidar in regional surveys

The first group of papers examines the use of lidar in archaeological surveys organized on a regional scale. Lidar work by the Deutsches Archäologisches Institut in the Kephissos Valley of Phokis began in 2018, in collaboration with the commercial operator Geosystems Hellas. This phase of the project follows a long history of research at several sites in the region, where lidar was introduced as a valuable tool to be used alongside other forms of remote sensing, most notably

[27] The full program can be viewed here: https://www.ascsa.edu.gr/events/details/lidar-and-landscapes-in-the-archaeology-of-greece-an-international-workshop. Not all papers presented at the conference are included in the present collection.
[28] Haagsma *et al.* 2025.
[29] Lupack *et al.* forthcoming.
[30] Karamitrou *et al.* 2024;

Figure 5. Recent and ongoing archaeological lidar projects in the Cyclades, showing also the size of the project area and method of data acquisition.

multispectral satellite imagery analysis and geophysical survey.[31] In their contribution to this collection, Sporn and Kennedy present impressive results across multiple scales (architectural, settlement, regional), especially through the use of Simple Local Relief models (SLRs) to map buildings, town plans, fortifications walls and more at Elateia, Agia Marina, Palaiothiva, and the sanctuary of Athena Kranaia. Methodologically, they demonstrate the importance of combining different types of remote sensing and also discuss situations where lidar did not detect significant features, as in the case of a temple discovered by the project at Modi.

Fachard, Chezeaux, and Castiello discuss the recent work of the Eretria-Amarynthos Survey Project, carried out by the Swiss School of Archaeology in Greece in the region between the Eretria and the sanctuary of Artemis Amarysia at Amarynthos.[32] Here, lidar was used alongside the archaeological field survey to identify areas of interest, as well as to study the wider region and zones that are

[31] E.g., Sporn 2022.
[32] E.g., Fachard *et al.* 2023.

not typically subject to pedestrian survey in the Mediterranean (mountainsides, wooded slopes, etc.). This 'lidar-led' approach to regional survey also provided a first opportunity for Sylvian Fachard, Thomas Garrison, and myself to form a research group to adapt methods first deployed in Mesoamerican contexts to a Mediterranean one.[33]

My own work with the Small Cycladic Islands Project (SCIP) is a collaboration with colleagues from the Ephorate of Antiquities of the Cyclades and Norwegian Institute at Athens; since 2019 we have carried out surveys of 87 small, currently uninhabited islands and acquired lidar data over more than 100.[34] In the present paper, we examine lidar data collected in 2022 *after* pedestrian survey was carried out on several islands between 2019 and 2021, in order to quantify how much more lidar shows us in comparison to the results from pedestrian survey alone.

A second paper by the SCIP team (Manquen *et al.*) examines issues of issue of quality control in a dataset that was first investigated with lidar, then surveyed, drawing on work by Garrison and colleagues in the Maya Lowlands.[35] Here, we aimed to test the accuracy of lidar-based feature identification and feature classification via a systematic approach to ground truthing. This fieldwork allowed us to identify rates of true positives (correct identifications), false positives (lidar-based identifications that proved erroneous in the field), and false negatives (features identified in the field that had not been recognized in the lidar analysis). These data provide insights as to what types of features can be easily identified in lidar (e.g., terraces) and what types are more challenging or impossible to recognize (small, irregular, or flush-with-the-ground constructions).

The final regional survey described in the volume is the Samothrace Lidar Project, a collaboration between several scholars (Dimitris Matsas, Bonna Wescoat, and Chris Witmore, with Michael Page, Brody Manquen, and Tom Garrison), which builds upon archaeological survey of the island in the 1980s and ongoing work at the Sanctuary of the Great Gods.[36] This new project focuses on zones of known archaeological sites, especially of classical and prehistoric periods, which remain under explored because of rugged terrain and dense vegetation, as well as the wider agrarian landscapes of the coastal zones and flanks of Mount Saos. Spectacular results from various parts of the island highlight both the strengths of lidar and the necessity of ground verification, for example at the medieval village of Christos, where much of the settlement is visible in the lidar data, but much is also obscured by tumble and other cover like doorways and niches.

Lidar and the analysis of archaeological sites

We turn next to aspects of lidar analysis at individual sites. In the first paper, Thierry Lucas builds on previously published work at Akraiphia,[37] in order to stress the importance of archival evidence in comparing the results of lidar scanning with historical maps, field partitions, and more, in order to reveal the town plan of the ancient settlement with an unprecedented level of detail.

Next, Robin Rönnlund presents a lidar-based study of ancient Melitaia, part of a wider program involving surface collections, geophysical survey, and excavations. Here, lidar analysis revealed significant parts of the city plan, internal street grid, and fortifications, showing also how lidar analysis complements and can be used in tandem with other techniques.

[33] E.g., Canuto *et al.* 2018. Garrison, a specialist in Maya archaeology, remains a key collaborator for the projects in Euboea, the Cyclades, and Samothrace, not least as the director of the Lidar and Landscapes of the Ancient Mediterranean and Americas (LLAMA) Laboratory at the University of Texas at Austin.
[34] E.g., Athanasoulis *et al.* 2021; Knodell *et al.* 2022; Knodell *et al.* 2025
[35] Garrison *et al.* 2023.
[36] E.g., Matsas *et al.* 2023; Wescoat 2017.
[37] Agapiou *et al.* 2022; Lucas and García Sánchez 2022.

Zozi Papadopoulou and colleagues focused on the documentation and quantification of archaeological features on the island of Rheneia, a tremendously dense built environment. On an island of c. 14 km^2, nearly 3000 features were mapped in the course of lidar analysis, with a total length of over 340 km. With features so tightly packed together, it is often difficult to distinguish between older (ancient) and more recent constructions. The present paper examines four particular sites – the necropolis of the Delians, access points to this zone from the north and south, and ancient and modern farmhouses at Pikragouria – in order to make such distinctions and highlight where lidar can (and cannot) contribute new knowledge to a landscape that has been subject to various types of excavation and survey work for more than 100 years; the lidar analysis is done in collaboration with the first systematic, intensive survey of the island as a whole.[38]

UAV lidar surveys

The next group of papers presents case studies that deployed lidar sensors on UAVs, and includes also comparisons between drone-based lidar and aerial photogrammetry. Such explicit comparisons highlight different processing techniques and types of software for handling point cloud data and visualizations, as well as some surprises about the (actually very good) quality of photogrammetric data even in heavily vegetated contexts.

Waagen and colleagues provide an open-source workflow for drone-based lidar acquisitions, based on long-running work in the area of ancient Halos. The authors examine several sites across a well-documented archaeological landscape, including habitation sites, fortifications, and a funerary landscape, ranging in date from the Neolithic to medieval periods. They demonstrate the value added by applying drone-based lidar scans, even long after initial fieldwork has taken place, to a number of different types of sites and periods.

Levine and colleagues also focus on drone surveys, but turn to a particular type of landscape: the Naxian marble quarries at Melanes and Apollonas, most famous for the monumental kouroi sculptures abandoned in them after breaking. The project focuses on detailed documentation of the quarries and their environs, including pedestrian survey, sculptural and architectural analysis, and drone-based lidar and photogrammetry. In their paper here, the authors carry out an exhaustive program of comparing lidar and photogrammetry data collection and processing techniques that will allow future researchers to choose a combination of methods that best suit the landscapes and features they are hoping to interpret.

Another drone-based lidar survey of quarries is described by Pike and others, who focus on the ancient white marble quarries on Mt. Penteli – perhaps among the most studied and most significant in the ancient world (certainly the most visited by groups of students). This project builds upon the seminal work of Manolis Korres and his earlier efforts to map these quarries and understand them as landscapes of production.[39] This paper also highlights some of the challenges of low altitude drone surveys in highly varied topography.

Together, these papers demonstrate the importance of selecting methods and tools based on the scale of analysis and research questions at hand. For teams working in a small area, a large, expensive aerial lidar acquisition probably is not the best solution and indeed lidar in general may not be the best solution, when a comparable, in some cases even better, dataset can be obtained through photogrammetry. At the same time, larger study areas (more than a few square kilometers) are still quite difficult to cover via drone survey alone.

[38] Papadopoulou *et al.* this volume.
[39] Korres 1995.

Beyond Greece: perspectives from the wider Mediterranean

The final two papers look beyond Greece to consider disciplinary and interpretative questions. In the first, García Sánchez and colleagues compare lidar use in various Mediterranean contexts, drawing contrasts between Spain (where open lidar is widely available) and Portugal, where coverage is expanding but not yet at the same level. Both situations are markedly different from Greece, where coverage is piecemeal and privately controlled. The obvious result is major difference in the types of questions that can be asked of archaeological projects that make use of lidar data.

The work of Giacomo Fontana, who also participated in the 2024 conference, should also be mentioned here, though it is previously published and therefore not presented in this collection.[40] Again, we have a case from outside of Greece that demonstrates the tremendous potential of lidar to address research questions beyond the individual site. This work on Italian hillforts illustrates the power of truly large-scale regional analysis, having identified over 300 potential hillforts, across an area of c. 15,000 km^2. From there, Fontana has been able to address questions of sociopolitical organization and produce training data for classifications with artificial intelligence (AI). It also highlights the opportunities provided by openly available lidar data, which does not currently exist in Greece.

The final paper zooms in on Croatia, where Nives and Michael Doneus have been at the forefront of archaeological lidar research for over a decade.[41] The Mediterranean landscapes of Croatia are obvious points of comparison for Greece, and it is hoped that the innovative work of Doneus and Doneus can be taken up by researchers here, for example regarding chronological interpretations – stratigraphy and phasing – derived from lidar scanning and a field program of OSL dating and profiling of terraces and other rural structures meant to test the application.[42] In the present volume, Doneus and Doneus present the experiences of the last ten years on the north Adriatic coast and the considerable potential of ALS and ALB (Aerial Lidar Bathymetry) for the study of Mediterranean landscapes for archaeological purposes.[43]

Discussion and considerations

With these examples in mind, a few 'big-picture' takeaways and concerns for the archaeological use of lidar in Greece merit further discussion. Some of these are also of much wider disciplinary relevance and are considered in a recent review by Inomata.[44] The first and most obvious concerns data availability. There are no publicly available lidar data in Greece. Perhaps at one point there will be, but for now it can be acquired only by specialists with drone lidar units or by commission from private companies, such as AeroPhoto and Geosystems Hellas. In this way Greece is considerably different from most western European countries. Vinci and colleagues classify lidar availability in Greece as 'restrictive', while nearly every country north and west of the Balkans has either open or partially open lidar availability (in this context partially open means that lidar is available for certain regions and/or through case studies acquisitions).[45]

Data availability also relates to questions of scale and the appropriateness of different methods for different scales of analysis. We might think about feature, site, landscape, region, and macroregion as different scales of analysis. Lidar is appropriate for all of them, but how one acquires data obviously depends on what one wants to do with it. The explicit comparison of methods for drone lidar and photogrammetry by Levine and colleagues is a great service in that they can now

40 Fontana 2022, 2025.
41 E.g., Doneus and Briese 2011; Doneus *et al.* 2013; Doneus *et al.* 2022.
42 Doneus *et al.* 2022.
43 See also Doneus *et al.* 2013.
44 Inomata 2024.
45 Vinci *et al.* 2025: figure 6.

be drawn upon by other researchers. We have some examples of such comparative work from contexts in the US, for example at Cahokia, but not from Mediterranean environments.[46] One thing missing in Greek contexts is truly regional scale applications, across very large areas. Some recent projects are touching on this – in Samothrace, the Kephissos Valley, Euboea, and the Cyclades – but even in these cases we are still in early days, focusing primarily on the documentation of architectural features, rather than large-scale regional patterns. The largest study area described in this collection is about 240km^2 (of lidar coverage). By contrast, Fontana's study of Italian hillforts involved a study are of about 15,000km^2, and was therefore able to introduce an entirely new range of large-scale research questions.[47] Such a large-scale analysis would probably be achievable only with publicly available data over wide areas and using advanced computational methods, though there are examples from elsewhere, such as Guatemala, of consortia of projects that have pooled resources and sought collaborative funding to sponsor large acquisitions of over 7000km^2 in the Maya lowlands.[48] Such a collaborative project may be possible in a Greek context, but that would depend also on a regional outlook and interest in continuous coverage that historically has not been strong in Greek archaeology. Because of survey permit areas being restricted to 30km^2, most projects are designed with research questions that fit that relatively small scope, so a map of Greek surveys looks more like discontinuous patches than contiguous zones with shared borders.[49]

In remote sensing, the use of multiple methods has the best chance of yielding significant and reliable results.[50] Papers in this collection combine lidar analysis with RGB aerial photography, historical photography, multispectral satellite imagery, and even geophysical survey. The same applies to the importance of using multiple visualizations derived from the same and different data sources (DSMs, DTMs, DFMs).[51] We should highlight especially the importance of historical cartography, with which Greece is quite well endowed. The urbanization of Greece is a relatively recent phenomenon, with most of the widespread landscape impact happening only from the second half of the 20th century onward. There is therefore a rich archival record of what the Greek countryside looked like that simply cannot be reproduced – but can be usefully combined – with modern forms of remote sensing. We should also consider the benefits of multi-spectral lidar, which combines the three-dimensional mapping capabilities of ALS with the analysis of images across different wavelengths and remains underutilized in archaeology globally.[52]

Several aspects of lidar interpretation also merit consideration here. I focus mainly on issues that are not well represented in the papers that follow, but that we should contemplate as we move forward. One is the form in which we actually look at the data – most archaeologists are working from visualizations derived from DSMs, DTMs, DFMs, and aerial imagery. These are two-dimensional rasters that fall within the comfort zone of most GIS savvy archaeologists. We probably need to do more with point cloud data. This was evidenced in the work that AeroPhoto – the true geospatial professionals – presented at the conference, and it is also clear in publications from specialists in remote sensing.[53] Point cloud data tends to be underutilized by archaeologists, who are more familiar (and comfortable) with 2D raster visualizations. Of course, it is not necessary to be a specialist in archaeological lidar or remote sensing in order to make use of these data (though there is certainly a learning curve). One can be a productive lidar data user without being a developer; nevertheless, we should look to developers for guidance and seek out productive collaborations. Of great use will be a newly published set of guidelines for lidar use and interpretation from the

[46] Vilbig *et al*. 2020.
[47] Fontana 2022.
[48] Canuto *et al*. 2018.
[49] Knodell 2021: 34, map 3; Knodell 2025.
[50] E.g., Laugier and Casana 2021.
[51] Kokalj and Somrak 2019.
[52] Fernandez-Diaz *et al*. 2016; Takhteshha *et al*. 2024.
[53] White 2013; Richards-Rissetto *et al*. 2021; Štular *et al*. 2021a.

European Archaeological Commission.[54] Another key theme that needs more attention is the quality control – that includes ground verification, of course, but also some study of what types of features can be more or less reliably detected by lidar.[55]

AI has much potential here for feature recognition and classification, but that has yet to be realized in any widely applicable way. Several recent papers describe training datasets and machine-learning or deep-learning models, but these are often either too specialized to a particular dataset, which results in an increase in false negatives in areas with different terrain, or too prone to identifying false positives. [56] At present there are no 'out-of-the-box' solutions that have been deployed beyond an individual case study. Nevertheless, the careful ground work of digitizing features and areas of interest manually still bears rich fruit, as seen in several of the papers that follow, which have classified dozens or hundreds (collectively thousands) of kilometers of archaeological features.

We must also consider the matter of classification standards and data transferability, along with verification and ground truthing. This theme echoes broader conversations over the last decades in Mediterranean survey and an emerging consensus with respect to FAIR standards for data management and archiving (that data must be Findable, Accessible, Interoperable and Reusable).[57] At a minimum, projects must publish specific parameters of data acquisition and their datasets, and should provide detailed, replicable descriptions of their methodologies. It would also be useful for projects to make available database templates, so that researchers working on parallel projects can easily generate comparable datasets. While the field has made considerable advances in recent decades toward archiving field data, archaeologists have not (as a field, at least) come up with uniform standards for archiving the huge datasets associated with remote sensing projects. Even if standard repositories cannot accept hundreds of gigabytes of lidar data and derivative products, project leaders must come up with archiving plans and publish them, in order to ensure access for future scholars, local communities, and other stakeholders.

Another set of interpretative issues concern phasing and temporality. These themes are addressed by Doneus and Doneus, but they really apply to all of the studies in this collection. Lidar images – like a landscape – are by nature a snapshot, capturing a particular moment in time. They may equally be considered multitemporal, containing an amalgamation of remains from many different periods. But how can we make sense of this accumulated palimpsest? Is it worthwhile to think about phasing with remote sensing data alone, or is this something that can only be examined in the course of ground verification? These questions have been explored previously in the Maya area, as well as in other Mediterranean contexts.[58] We can see in the present papers that high-resolution lidar can be used not only to distinguish between phases and observe long durations, but can also provide important insights that would not be visible on the ground. This is challenging, to be sure (and going from phasing to chronology is another matter), but it is important.

Finally, future work should give serious thought to issues of data publication and remote sensing ethics. A recent special issue of *Archaeological Prospection* explored remote sensing ethics generally,[59] as well as in the particular contexts of large-scale projects in North Africa and the Middle East,[60] North America,[61] and in the particular case of sacred spaces.[62] What are the particular implications of open data for cultural heritage management in Greece? What are the ethics of lidar acquisition,

[54] Bennett *et al.* 2025
[55] See especially Manquen *et al.* this volume.
[56] Somrak *et al.* 2020; Guyot *et al.* 2021; Olivier and Verschoof-van der Vaart 2021; Mazzacca *et al.* 2022; Kokalj *et al.* 2023; Character *et al.* 2024.
[57] E.g., de Haas and van Leusen 2020.
[58] Garrison *et al.* 2019, Doneus *et al.* 2022.
[59] Davis and Sanger 2021.
[60] Fisher *et al.* 2021.
[61] Johnson *et al.* 2021.
[62] Davis *et al.* 2021.

use, and publication? How would that change with the introduction of public or semi-public lidar data? Looting will always be a concern with open-access lidar, and rightly so, especially for government institutions and offices responsible for protecting cultural heritage. Nevertheless, I believe that there is a strong argument to be made for open or (perhaps better) semi-open data and making resources available also to researchers in other fields, but this needs to be carefully negotiated with the relevant authorities in the Ministry of Culture and local ephorates.

Conclusions

In sum, there is still much work ahead, but the papers in this volume also provide us with a set of clear, positive conclusions concerning archaeological lidar in Greece. Most obviously, lidar works, and adds a dimension to landscape and regional-scale architectural documentation that would not be achievable through other means. While most Mediterranean landscapes are not hiding entire cities, as under the jungle canopies of Guatemala or Cambodia, even the relatively sparse vegetation of the Cyclades obscures features, sites, and especially systems of land-use that are revealed through this form of remote sensing. Indeed, the low, dense vegetation common in Greece (and elsewhere in the Mediterranean) presents particular challenges, which several papers in this collection aim to confront. Lidar is also an effective tool in the face of reforestation and the abandonment of hill land that is not suitable for machine-based farming; the growing difficulty of access to such landscapes (especially via traditional pedestrian survey) is an issue across the Mediterranean.

Second, lidar has a significant value-added effect even in areas where systematic fieldwork and remote sensing has been carried out. The benefits are clear in terms of both checks on our field methods and providing new qualitative and quantitative data for spatial analysis. It therefore offers modes of analysis and levels of detail not possible with other methods. That said, lidar is not a cure-all, and does not replace other forms of remote sensing, especially at a small scale. Crucially, ground truthing and self-assessment remain essential, especially as new research teams seek to hone these techniques.

The greatest potential of lidar analysis in Greece has yet to be realized, especially if public or semi-public data become available at some point. AI holds much promise for large-scale analysis, to be sure, but this is meaningless without an understanding of how to interpret and evaluate such automated analysis. For the present we will all benefit by identifying common problems and sets of good practices. Researchers working with lidar in Greece need to continue sharpening our analytical skills, developing new research questions, learning from our colleagues in regions with deeper histories of archaeological lidar research, and facilitating data comparability. Only then can we make the most of these tremendously rich datasets and take advantage of new analytical capabilities and data availability when the time comes.

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