ISSN 1756-753X

AARGnews

Number 59 October 2019

Contents

AARGnews is the newsletter of the Aerial Archaeology Research Group

Published twice yearly in April and October

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Cover photo:
Flying home after AARG 2019 over one of the windfarms off the Suffolk coast.
Photo: Rog Palmer: 18 September 2019.

Editorial [1]

In June 2019 I was in Constanţa with Carmen Miu while she was checking a few things in preparation for the September conference. During a meeting in Romanian with Sorin Colesniuc my thoughts wandered away from present-day AARG and I wrote some notes which are slightly edited and expanded below and bear some relevance to discussions at AARG in September:

> Is there a struggle for AARG to keep up with its pretentions?
> Initially we had 'meetings' but when Toby Driver became Chairman, these were changed to 'conferences' and since then we have tried to live up to that somewhat grander name and all its meanings. A 'conference' may make it easier for those with jobs to claim payment and time off work, but 'conference' also anticipates high-quality papers, smart venues and smoothly-flowing administration. Is this really AARG?

AARG is a small group of specialists and/or enthusiasts who are drawn together through various aspects of aerial capture of data (how's that for a vague description?). I think that we thrive on discussion rather than smooth presentation and because of the small size of the group many of us have become friends as well as colleagues. Interest is generated, progress may be made, knowledge may be gained, through talk rather than through satisfied completion of projects, however interesting they may be.

Perhaps an under-organised AARG rather than one that was super-efficient may make for more positive results. Do we rate conferences in terms of results? No, but AARG originally was created to talk about problems and we seem to have lost that part of our meetings. At Constanţa there was some talk about changes to AARG and perhaps the inclusion of some 'what the hell is this?' questions about aerial images would be a welcome way of showing that we do not know everything as well as being fun for participants.

Thoughts on futures for AARG also came into the conversation that Darja and I had in September 2018 (see *AARGnews* 58 and this issue) and one thing that was clear is that once you look at continental Europe there seems to be a general disbelief in aerial information. Often this is not believed to be archaeological until there has been 'ground truthing' (bleugh) to confirm matters in the way that conventional archaeologists seem to need to do. So there is a need to educate archaeological curators and heritage people about the facts of aerial information. In 1998, one of the first training schools was specifically for Polish heritage inspectors. However, we teachers were still learning the ropes then and it was very much an Otto-led enterprise to show them the value of flying and aerial photography, most of which was irrelevant to inspectors who may need a special school designed to show the advantages that existing aerial images can make to: 1) their existing archaeological record, and 2) provide knowledge in advance of excavation. They do not need flying, they do not necessarily need to learn how to interpret and map, but they do need to be shown the difference and advantages that come from use of and belief in aerial information. AARG membership includes those with suitable knowledge to run such a course if the interest could be generated to attend it.

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Where have the aerial photographs gone?

Recent years have seen a predominance in archaeological use of ALS data. We've been given a lot of AARG presentations on this and it reflects (perhaps) two things: that there may be money in using new technology and, a bit more worryingly, that we can play games with ALS and forget about the previous 100 years of data collecting. Of particular note has been the deluge of 'experimental' work using ALS data, by which I mean its use in various AI trials. There's nothing wrong with that as an occasional attempt but it does make me wonder if the methods being developed will be of any use on plain boring two-dimensional images of which we have many. Or are people waiting for unborn technology to come along and convert those (often) single views into 3D visualisations that can be treated in the same was as ALS? It does get slightly worrying when, for example, trials using ALS in one place seem to be made to reflect work for a whole country in which a lot of information will come from old aerial photographs. Is anyone carrying out similar experiments using only images?

JNH – a personal reminiscence

Within the Civil Service, or certainly the UK's version of it, was the common use of initials to identify people, thus John Hampton was tagged, and often referred to as, JNH. As this issue was going to bed, news came through of his death at the age of 97. John, perhaps unknown to the current generation of AARG members, was the person who had the vision to take 'aerial archaeology' from its simplistic role of producing aerial pictures of single sites to becoming sources for interpretation that enabled their conversion and combination into mapped archaeological landscapes. Nowadays, the transformation and mapping may all be done in GIS but when I started work for him in 1968 it was done slowly, painstakingly, by hand and John checked that every wiggle in every line was correct.

Without John, 'aerial archaeology' may still have remained just a way of 'discovering sites'. At the APU (Air Photographs Unit as it was then called, now (possibly) Aerial Investigation and Mapping, within Historic England), he changed the way that flying and photography was done and ended up with kit and method that satisfied his need for stereo pairs or runs of photos while keeping the images as near to vertical as possible by dangling the photographer out of the aircraft. His photographs were taken with mapping in mind so usually included control points as well as archaeology. He flew at a height that would give him images at about 1:2500 scale when printed on 9x9-inch paper so that any large-scale mapping would not necessitate enlarging image details. And anyone who has worked with those photographs alongside smaller images will know what an advantage that increased size makes to perception and interpretation. John's post as head of RCHME's APU also included building up the archive collection which he did by writing to every aviator who may have flown with a camera and also contacting the then small number of local fliers and coming to arrangements through which their photographs would become part of that archive. Those few fliers, thanks to help from John and RCHME, had grown to about forty by the mid-1970s and their surveys of local areas added considerably to the extent of England that was photographed each year and thus to enlargement of the archive of aerial photographs.

I owe John a debt of gratitude because, when I was fairly fresh from an engineering apprenticeship and with a beginner's interest in archaeology, he took me on as his cartographic draughtsman when only one other person was employed in the APU. There wasn't a formal interview as such but the one key question I remember was him asking if I liked doing jigsaw puzzles – something that I now ask anyone new to the game. It is that attitude – attention to detail, patience, keeping an open mind – that is necessary for good photo interpretation. John built up staff numbers in the APU and started small mapping projects. He made it clear that these were only 'interim statements', never the absolute truth, and in turn those small projects led to the English National Mapping Programme (or whatever it is called today) and the pinnacle of mapping set by Cathy Stoertz's (1997) *Yorkshire Wolds* book.

JNH with the cake he commissioned for the APU's 50th birthday, 1 November 2015.

John Hampton was a founder member of AARG and also attended the pre-AARG meetings. In those early days, his contributions to discussions on drawing conventions, classification, scales and mapping accuracy helped consolidate the ways in which many of us now think and work. AARG elected him as an Honorary Member way back in time (I don't think we keep a record of such things but it is likely to be marked in a past *Editorial* if anyone wants to trawl through the past 58). John seemed to be a reluctant writer and published little, but his history and development of the APU can be read in his 1989 paper, and HE's celebration of 50 years of flying includes a version of their origins, of flying, the archive and mapping (HE 2019 – thanks to Helen Winton for reminding me of this).

References

Hampton, J.N., 1989. The Air Photography Unit of the Royal Commission on the Historical Monuments of England 1965-1985. In D. Kennedy (ed) *Into the Sun: essays in air photography in honour of Derrick Riley,* 13-28. Sheffield: J R Collis.

HE 2019. 50 Years of Flying for Heritage https://historicengland.org.uk/whats-new/research/50-years-flying/

Stoertz, C., 1997. *Ancient landscapes of* the *Yorkshire Wolds*, RCHME, Swindon

This issue

It has been usual (rather than written in stone) for recipients of grants/scholarships to attend AARG meetings to thank us for those grants by contributing to AARGnews. This issue is slimmer than expected because most the people we helped this year didn't even bother to reply to my email requesting their contributions. We have the posters, plus some extra ones from AARG 2019, but we do not have the papers presented. AARG's committee should try and find a way to ensure a positive response from those we aid.

In print, Roland Linck and Sarah Abandowitz take us, via aerial photographs, to a POW camp at Bad Aibling, Germany; Geert Verhoeven adds another part to his 'pixel corner' (and if you read nothing else of that, please look at the last paragraph); and we have far too many books and papers listed. Posters are in alphabetical order of the first named author.

Chairman's Piece

Steve Davis[1]

In the last year or so the AARG committee have sought opinion on two matters that are, in our opinion, of significance to you, our members. These are 1) the timing of the conference and 2) whether we collectively feel that an annual conference/meeting is a sustainable and desirable goal. Initially we had something of a rangefinder attempt using SurveyMonkey, with a more concerted vote taking place at this autumn's conference in Constanta.

The rationale behind the idea of possibly moving the conference is that September has become something of a conference silly season in the last few years, with some direct 'competitors' (of which more later) occupying slots very close to AARG. So, this year we had ICAP, EAA and AARG; last year LAC, EAA and AARG and so on. Potentially moving away from the September slot might remove a degree of conflict from some members who feel the need to be at all of these, or at least at more than just AARG. From the rangefinder survey there was a vague consensus that May would be a good time to move to; however, come Constanta the vote was clearly to 'remain' (of course, we are all a little more wary of leave/remain votes than we used to be…). So, there is no remit for a move away from September.

The second issue was, and continues to be somewhat more emotive. For context, again, the straightforward idea was to move AARG to an every other year model so it alternates with ICAP. This was not, I should stress, in any way a motion to merge the two organizations, but perhaps a way of us, in non ICAP years, getting a slightly higher proportion of ICAP members than we currently do.

Again, the vote here was a close one of Brexit proportions. While a tiny majority voted in favour of the motion it was slim enough that a couple of members would have swung the percentages the other way. It should also be stressed that total turnouts for voters were around 65%. Again, the outcome here is far too close for us to claim any kind of mandate to make such a decision – as such we will remain an annual event for the time being. I should also point out that members attending the annual conference voted far more strongly to retain it than those who were not present at the meeting.

That said, I think it is fair to say that from the floor there is an appetite for change. As a community we have talked about training for a long time, and while that happened a lot more in the halcyon days of ArcLand, since then we have not engaged to any great extent. TRAIL for example does this admirably well, and manages a well-attended training school every other year, sometimes in quite difficult to reach venues. There is almost certainly stuff we can learn from this. I think what was also clear from the floor is that to most attending members is that many members do not view AARG as 'competing' with anything – to them it is a thing apart from the rest of the conference schedule. I can understand why this is not necessarily obvious to all, but since my first AARG in 1991 it has been very clear to me: AARG is not a competitor to EAA or ICAP, it has a distinct atmosphere (which I shall describe as 'nurturing') and group of attendees who set it apart.

Clearly this can't go on forever. There are fewer of the longstanding AARG members attending now than there used to be, and we need to make sure that a new generation of these

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is encouraged. This is against a backdrop where climate change and 'flight shaming' is becoming a genuine issue as regards small conferences especially – increasingly PhD supervisors are advising students to go to a limited number of very large meetings. So, change is not only good but I believe necessary.

To that end the committee have discussed financing or at least part-financing training events over the next few years initially, to run in tandem with more conventional conference programmes. This is still very much a development phase, and we are open to ideas and proposals for events (within reason). It should be stressed that this is in no way an 'easier ride' than organizing a conventional conference – far from it, but we strongly encourage you to submit ideas.

We are also entering a final conference for many on the current committee. Myself as Chair, Rachel as VC and Lenka as Secretary, not to mention Moira's exceptionally long final bow as treasurer – we welcome nominations and interest from members in any of these roles (with the exception of Vice Chair which the outgoing chair usually occupies). We look forward to seeing you in Trondheim next year.

AARG notices

The Derrick Riley Bursary

The Derrick Riley Bursary still exists. It is £500 a year, usually a single award, but sometimes is split and given to two people.

There is an application form at the link below on the Sheffield Archaeology Department website and a Riley Bursary page on the Sheffield website where potential applicants will be able to find information and download the application form.

https://www.sheffield.ac.uk/archaeology/derrick-riley-fund

Please apply for this even though it is not used only for conference attendance. AARG has limited funding and access to the Riley Bursary extends this amount to something more useful. No whinging about lack of money if you don't apply.

ISAP Fund

ISAP have a fund to provide support of up to £1000 to assist with members' projects [membership costs less per year than AARG does] that 'further the objectives of the Society'.

Guidelines and application form from the ISAP web site:

http://www.archprospection.org/isap-fund

Information for *AARGnews* contributors

AARGnews is published at six-monthly intervals. Copy for *AARGnews* 60 (April 2020) needs to be with me no later than **March 20, 2020**. Editorial policy (for want of a better word) tends to be that if I am sent interesting contributions they go in unless there's a danger of an issue overflowing. Instructions for contributors are no longer on the AARG website, but this issue may serve as a guide or more information can be sent on request.

Please do not use any 'clever' formatting and avoid footnotes.

Good-quality jpegs are suitable for illustrations. Tiffs are for archives.

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Mapping a post-WW2 Prisoner-of-War camp in Bavaria through aerial photography

Roland Linck[3] and Sarah Abandowitz

Introduction

Up to now, prisoner-of-war (POW) camps in Bavaria have rarely been declared as historical monuments. Therefore, the knowledge and research work spent on these sites in national heritage protection is limited. To gain more information on the structure and layout of one of these camps, we started an aerial photo rectification project to draw a detailed map.

The camp was established at a former German military airfield near Bad Aibling, a small town 50 km southeast of Munich, as a U.S. prison camp for German soldiers in early 1946. Named as PWE 26, temporarily there had been up to 100,000 prisoners at once. In total, around 750,000 soldiers were detained there until its closure, only some months later, in September 1946. Among them, there possibly had been famous persons such as Joseph Ratzinger, the later Pope Benedikt XVI, and the German author Günther Grass. During its existence, Bad Aibling had been the biggest POW camp in Southern Germany. As the surrounding area was later used by the CIA and the BND for secret service applications, nothing of the camp is visible nowadays.

During its short existence, it had been never photographed by the allied air forces and no contemporary map of the buildings had been drawn. Therefore, the only source of information on the buried remains is the aerial archaeology archive of the Bavarian State Department of Monuments and Sites in Munich. Here, this site was documented between 1981 and 2010 by the aerial archaeologists Otto Braasch and Klaus Leidorf (Fig. 1).

Results

Aerial photos, especially those taken during wintertime, show in detail the remains of the concrete footings as positive snow marks. We georeferenced and orthorectified several of them via QGIS (e.g. Fig. 1) to draw the first map of this POW camp. The results are described in the following paragraphs.

In the central part of the mapped area, the division of the camp in so-called 'cages', i.e. separately enclosed and fenced rectangular areas, is clearly identifiable (Fig. 2, blue lines). Nine of these enclosures still can be identified by aerial photography. Each cage consisted of 10 barracks (Fig. 2, yellow), where up to 110 men were detained under appalling hygienic

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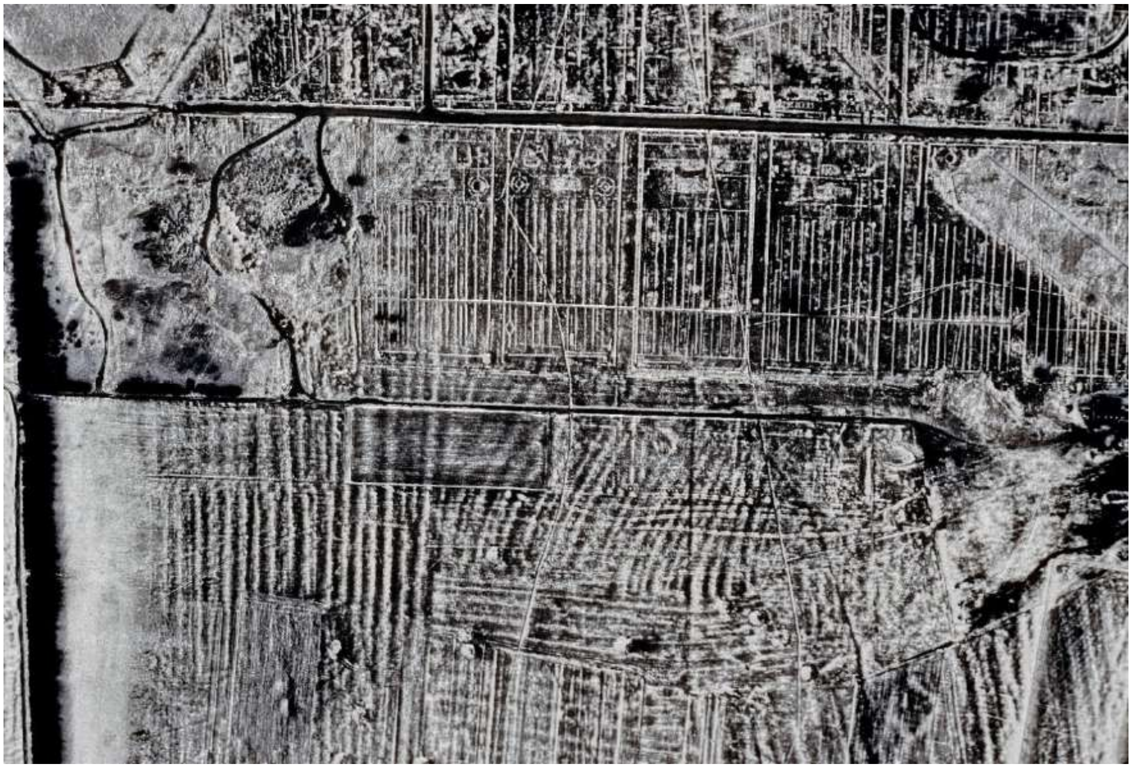


Fig. 1: Bad Aibling. Positive snow marks showing the buried concrete footings of the POW camp in an oblique aerial photo. Bavarian State Department of Monuments and Sites – Aerial Archaeology Archive, Inventory date: 22/01/1983, Otto Braasch, Archive-Nr. 8136/024 Slide 2731-12.

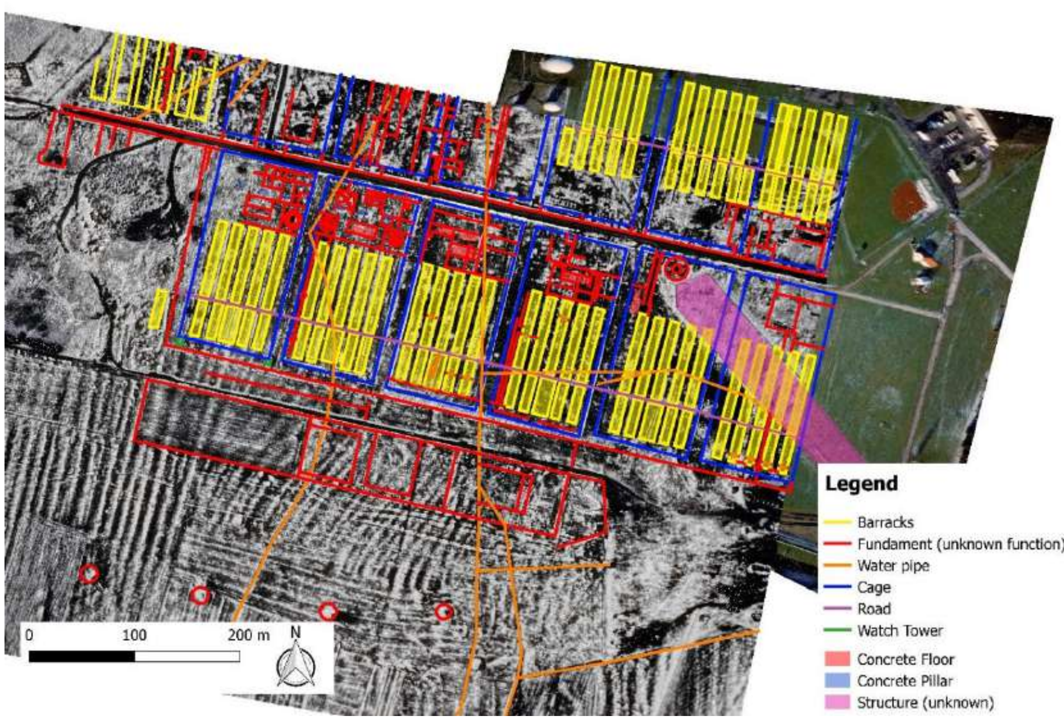


Fig. 2: Bad Aibling. Orthorectified aerial images showing the layout of the U.S. prisoner-of-war camp PWE26 as snowmarks. Overlay of two photos with the digital plan of the camp drawn in QGIS. Bavarian State Department of Monuments and Sites – Aerial Archaeology Archive, Inventory date: 22/01/1983, Otto Braasch, Archive-Nr. 8136/024 Slide 2731-12 & Inventory date 26/11/1995, Klaus Leidorf, Archive-Nr. 8136/024 Slide 7410-18.

conditions. The barracks north of the passageway (Fig. 2, violet) had a size of 77 x 8 m, the southern ones only half of it (35 x 8 m). Only the central barrack of the southern row of each cage is bigger and measured 25 x 14 m. Hence, the latter could have been a double-barrack or had a special function, e.g. for officers. At the southwestern most cage, the remains of two watchtowers (Fig. 2, green) can be identified. Below the whole area ran a network of former water and sewerage pipelines corresponding with the huts (Fig. 2, orange).

The main path through the camp possibly ran along the modern road. In the area of the cages facing this path, a multitude of further footing remains (Fig. 2, red) are detectable. The purpose of these buildings is not known due to the lack of contemporary sources. Perhaps, they were used as functional barracks like laundry, kitchen, bathes etc. or as guards' quarters. Furthermore, there are some quite 'strange' anomalies inside of three of the cages: concentric double-circular footings with a diameter of 15 m. The former use of these constructions, looking like target marks, is totally unknown. In addition, the use of the three regular bases of concrete pillars visible in the southwestern cages and having a size of 9 x 5 m remains unclear (Fig. 2, blue areas). Nevertheless, the possibility of their use to support floodlight installations of the German airbase is quite high. The big irregular area in the east of the camp that is running from northwest to southeast and is totally covered by snow in the corresponding aerial photo, is the remain of a platform used for approach lights of the airbase (Fig. 2, magenta).

Conclusion

For the first time, the orthorectification of the archaeological aerial images allowed the mapping of the surviving buried footings of the POW camp in Bad Aibling. This map can now be used for the detailed conservation of this historic monument of the post-war era in Bavaria and to inform the local people about this part of their history.

Resolving some spatial resolution issues – Part 2: When diffraction takes over

Geert Verhoeven

In part 1 "Between line pairs and sampling distances" of this split entry on spatial resolution, it was mentioned that this second part would focus on some fundamental laws of electromagnetic radiation to shed more light on the concepts of spatial resolving power and spatial resolution. The numbering of chapters, illustrations and equations simply continues so that one can easily merge both parts into one larger text. However, and in contrast to what was initially stated, this entry will not be the final part about spatial resolution. Because there is quite some, but still basic, ground to cover once the physical views on spatial resolution start to complement the geometrical ones, there will also be a third part. This approach also prevents any of these entries from becoming too lengthy.

3 Beyond pure geometry

To generate a sharp image with lots of details, it does not suffice to use a long focal length, get close to the scene or use a detector with a small detector pitch (as seen in part 1); one also needs a lens that can resolve fine object detail. This is of the utmost importance since the lens elements (and as we will see in part 3, even the sensor) blur the incoming radiation in unavoidable ways. To understand this blurring principle and its integration within the purely geometrical relationships introduced before, it is essential to know that an image is a visual representation of a specific physical object. Ideally, every object point is represented by an infinitesimally small spot in the image. However, the physical phenomenon of **diffraction** prevents this by turning every object point into a little blob.

3.1 Diffraction and the optical PSF

Every lens-based imaging system suffers from specific optical errors or defects. The generic name given to these lens defects is **aberration**. Longitudinal/axial and transverse/lateral chromatic aberrations occur when imaging a spectrum of different wavelengths. These **polychromatic aberrations** contrast with the **monochromatic aberrations** which occur even for incident electromagnetic radiation of only one wavelength. In total, there are five primary monochromatic aberrations, also known as the **Seidel aberrations**: spherical aberration, coma, astigmatism, Petzval field curvature, and distortion.

Even if one could make a lens devoid of all **aberrations** (i.e. a **perfect lens**), the diffractive nature of electromagnetic radiation would still put a physical limit on the smallest resolvable object. **Diffraction** is a phenomenon that comes into play because propagating electromagnetic waves bend in the neighbourhood of tiny obstacles and spread out when passing apertures. When imaging a single, distant point source of electromagnetic energy (such as a star), the resulting image is therefore never a perfect point but a diffraction pattern.

The spatial energy distribution of this image spot is called the **Point-Spread Function** (**PSF**). It describes the smear or spread in the sensor plane introduced by the optical chain. If the imaging system is aberration-free and only limited by diffraction, the three-dimensional PSF of a perfectly focused point is a so-called **Airy diffraction pattern** (Figure 7A). This Airy pattern geometrically describes the best-focused spot of electromagnetic radiation that a perfect lens with a circular aperture can generate. In the plane of the image sensor, the irradiance distribution of the Airy pattern looks like a bright circular central patch (the **Airy disc**) and a series of dimmer concentric rings, each ring separated by a circle of zero irradiance (Figure 7B & 7C). The pattern and disc were named after George Biddell Airy, a nineteenth-century English astronomer who was the first to calculate this irradiance distribution.

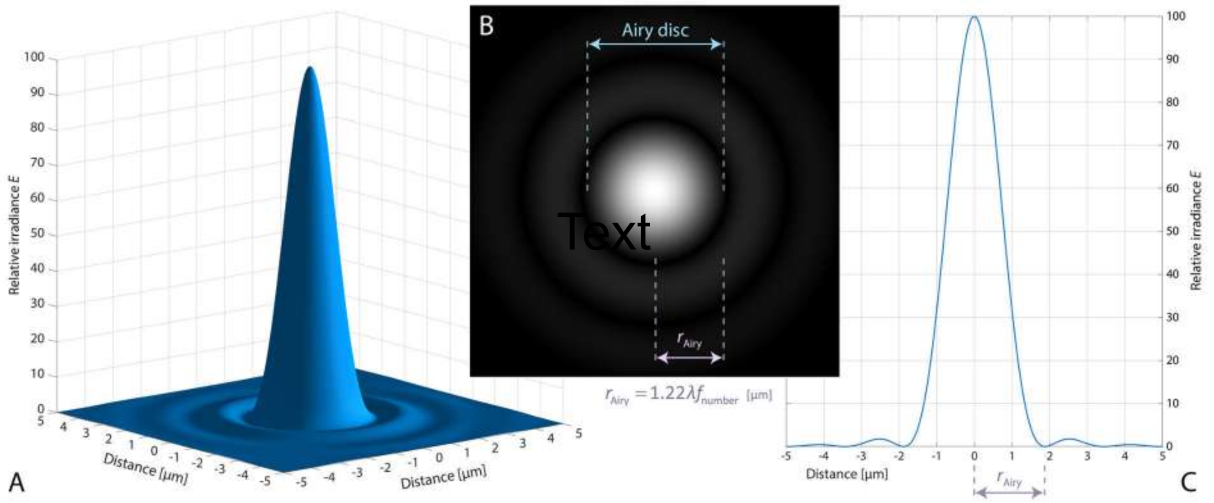


Figure 7 Inset A depicts the three-dimensional Airy diffraction PSF (at 550 nm and *f*/2.8), whereas B shows the two-dimensional PSF (slightly contrast-boosted) as seen in the image plane. Notice the high-irradiance circular Airy disc. Inset C illustrates a profile through the centre of the PSF. In B and C, the radius of the Airy disc is indicated.

The Airy disc contains about 84 % of the Airy pattern's irradiance, and its linear radius *r* equals:

$$r_{\text{Airy}} = 1.22\frac{\lambda f'}{D} \ [\mu\text{m}] \qquad \text{<11>}$$

The spread of the imaged object point thus depends on:

- the wavelength of the electromagnetic radiation (λ);
- the lens' focal length (f');
- and the diameter of the lens aperture (D).

For the lens of any photo camera, the latter two quantities f' (or simply f) and D are always combined in a **relative aperture** (e.g. *f*/2.8 or *f*/8). Photographers use these relative aperture statements simply because it would be hard to remember the exact physical dimensions of every lens aperture.

Using an aperture statement relative to the focal length also has the substantial advantage that any lens using that particular aperture (e.g. *f*/8) will transmit the same amount of electromagnetic radiation, irrespective of its focal length. For instance, a 130 mm lens with a relative aperture *f*/2 has a physical aperture diameter of 65 mm (130 mm / 2), while a 50 mm lens at that setting features a 25 mm aperture diameter (50 mm / 2). Those specific combinations of physical lens aperture size and focal length create the same angular aperture size, which in turns explains why the light transmitted by any *f*/2 configuration will result in the same exposure (that is, ignoring minimal differences in the lens' efficiency to transmit electromagnetic radiation) (see Figure 8 for a graphical explanation).

The numeric part of such an aperture statement is the **relative aperture number** or ***f*-number**. One can find a standard aperture series (*f*/2.8, *f*/4, *f*/5.6, *f*/8, *f*/11) engraved on many photographic lenses. This information now allows us to rewrite equation <11> for normal photographic purposes:

$$r_{\text{Airy}} = 1.22\lambda f_{\text{number}} \ [\mu\text{m}] \qquad \text{<12>}$$

The diameter of the Airy disc is then just twice the Airy radius or:

$$d_{\text{Airy}} = 2.44\lambda f_{\text{number}} \ [\mu\text{m}] \qquad \text{<13>}$$

Note that smaller wavelengths (e.g. ultraviolet radiation) and large lens apertures yield smaller Airy discs, and that both variables can be used to minimise the size of the image spot.

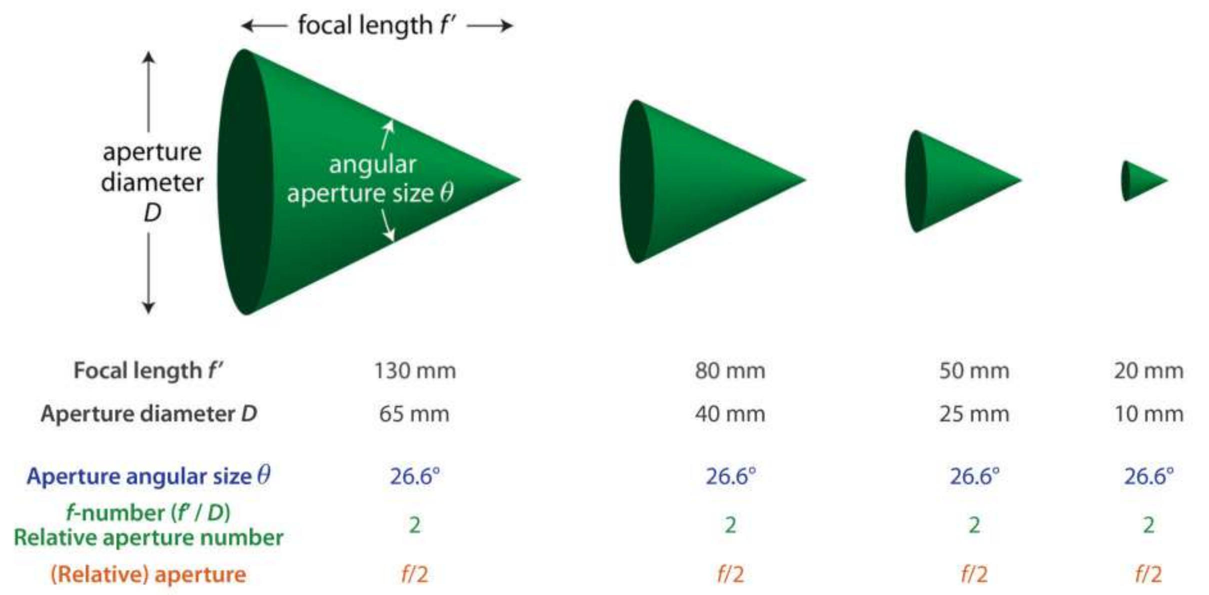


Figure 8 The concept of relative aperture. If lenses with different focal lengths feature the same angular aperture size, their relative aperture number and *f*-number are identical.

Let us illustrate this with some examples. If we photograph something using a lens at aperture *f*/2.8 and the scene is illuminated with visible electromagnetic radiation (i.e. light) which runs from 400 nm to 700 nm (so 550 nm is the central wavelength), the radius of the Airy disc becomes:

$$\text{radius Airy disc} = 1.22 * 0.550\ \mu m * 2.8 = 1.9\ \mu m,$$

and its diameter 3.8 µm (see Table 2 and Figure 7). Reducing the aperture diameter fourfold to *f*/11 yields an Airy disc diameter of 14.8 µm. Switching the illumination for a near-ultraviolet source with a central wavelength at 360 nm decreases the Airy disc diameter to 9.7 µm (see Table 2 and Figure 9).

	Wavelength	Aperture	Airy disc radius	Airy disc diameter	$RP_{spatial}$
Starting situation	550 nm	*f*/2.8	1.9 µm	3.8 µm	526 LP/mm
Smaller aperture	550 nm	*f*/11	7.4 µm	14.8 µm	135 LP/mm
Shorter wavelength	360 nm	*f*/11	4.8 µm	9.7 µm	207 LP/mm

Table 2 Different apertures and wavelengths yield dissimilar Airy discs and various spatial resolving powers.

Please be aware that the numbers mentioned above, and the plots of Figure 9, are only for **diffraction-limited** lenses (i.e. perfect lenses whose performance is limited only by diffraction and not by any aberration) that image a distant point that is perfectly in focus. So even under these very hard to achieve circumstances, very small apertures (indicated by larger *f*-numbers; e.g. *f*/16 or *f*/22) will always yield big Airy discs, thus lowering the spatial resolving power (see next section). In more realistic imaging conditions with aberration-limited lenses, the diffraction-induced blur is even worse.

In many situations, the smallest spot one can image (given a particular part of the electromagnetic spectrum and a specific lens aperture) surpasses the sensor's detector pitch. For example: an Airy disc diameter of 14.8 µm at *f*/11 is triple the size of the 4.9 µm detector pitch of the Nikon D810. Section 4.4 will explain how and when this size difference can lead to a loss in resolving potential. The important message is thus that the physical nature of electromagnetic radiation sets a fundamental limit by blurring the image, preventing an exact point-for-point copy of the real-world scene. [Note that the next sections will often provide two equations: one applicable to all optical imaging systems, and a simplified version for photo camera lenses. Although standard photo cameras are optical imaging systems, we can simplify the equations because their whole operation revolves around *f*-numbers.]

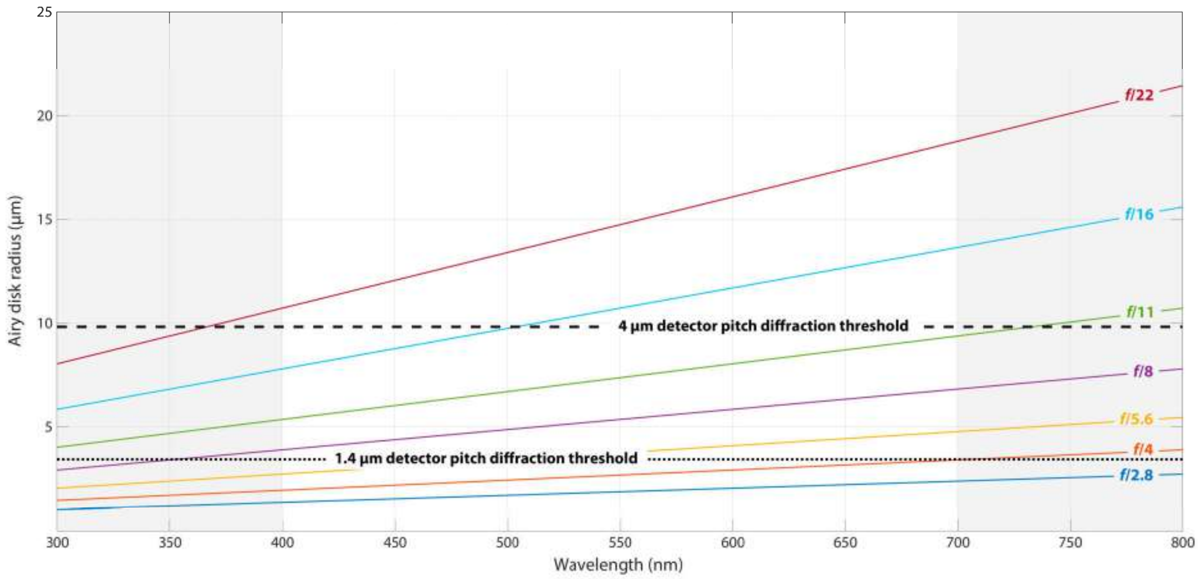


Figure 9 The influence of aperture and wavelengths on the Airy disc radius. The detector pitch diffraction threshold for two common detector pitches is indicated as well. The grey zones indicate invisible electromagnetic radiation.

3.2 Meet Baron Rayleigh

A scene is considered a collection of countless object point sources, and each of these sources generates a diffraction pattern with its amplitude proportional to the source´s radiance. The total radiance arriving at a specific point in the focal plane is nothing but the sum of contributions from all optical PSFs in the neighbourhood of that point. The unavoidable diffraction blurring by the lens has thus a direct effect on the amount of detail one can record and observe in an image, because it influences every imaged object point.

Obviously, smaller Airy discs yield a higher theoretical spatial resolving power of every optical system. However, even if the optical imaging system generates tiny Airy discs, diffraction patterns will always overlap in an image, and at a certain point, it will become more and more challenging to separate them (i.e. detect the presence of distinct objects – see the upper part of Figure 10). A prevalent metric to quantify the smallest spatial separation of two object points that still allows them to be unambiguously resoluted as two different points in the image is called the **Rayleigh criterion** (Figure 10).

Proposed by John William Strutt (Third Baron Rayleigh) in 1879, this criterion states that an aberration-free lens with a uniform circular aperture can spatially just resolve two adjacent point sources of electromagnetic radiation (that are incoherent, unpolarised, and of equal radiance) when the centres of their Airy discs are separated by the radius of the Airy disc r_{Airy} (Figure 10). When the separation distance between adjacent Airy patterns gets smaller than their Airy disc radii, the PSFs of the object points blend into an indecipherable blur, thereby rendering the point sources indistinct. Mathematically, this means that the superimposed Airy patterns must be separated by at least Δx_{min}:

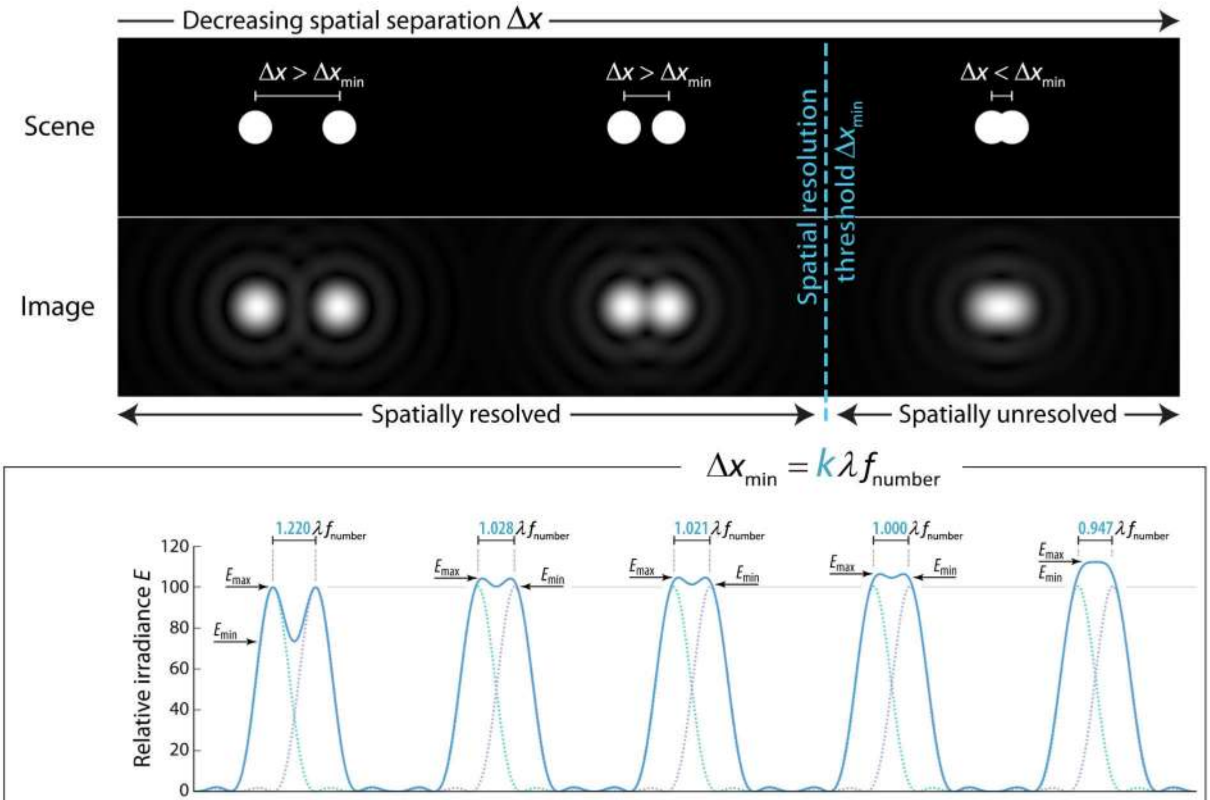
$$\Delta x_{min} = 1.22 \lambda f_{number} \text{ [µm] (for photo camera lenses)} \quad \text{<14>}$$

$$\Delta x_{min} = 1.22 \frac{\lambda f'}{D} \text{ [µm] (for optical imaging systems).} \quad \text{<15>}$$

This separation is known as the **optical limit of spatial resolution**. With the help of equation <3>, the **angular optical limit of spatial resolution** can be expressed in radians as:

$$\Delta\theta_{min} = 1.22\frac{\lambda}{D} \text{ [rad]} . \quad <16>$$

In other words: two point sources (or more general, objects) can be distinctly rendered by a perfect optical instrument only if their images on the sensor feature an angular separation that surpasses $1.22\lambda/D$. This short equation indicates that if one wants to obtain a smaller angular separation to render the final image more detailed, either the captured wavelengths λ must be shorter (e.g. blue light instead of red light), or the lens aperture D should be bigger (e.g. f/2.8 instead of f/11).



Criterion	Rayleigh criterion	Houston criterion	Dawes criterion	Abbe criterion	Sparrow criterion
Publication year	1879	1926	1867	1873	1916
Author	John William Strutt, 3rd Baron Rayleigh (1842-1919)	William Vermillion Houston (1900-1968)	William Rutter Dawes (1799-1868)	Ernst Abbe (1840-1905)	C.M. Sparrow
k-value	1.220	1.028	1.021	1.000	0.947
Contrast $E_{max} - E_{min}$	26.5 %	3.9 %	3.3 %	1.8 %	0 %
$(E_{max} - E_{min}) / E_{max}$	26.5 %	3.8 %	3.2 %	1.7 %	0 %
$(E_{max} - E_{min}) / (E_{max} + E_{min})$	15.3 %	1.9 %	1.6 %	0.9 %	0 %

Figure 10 Optical diffraction prevents a point-like irradiance distribution of imaged scene points. Resolving two scene points with a lens is only possible when the spatial separation between these fuzzier image renderings is large enough. This figure provides the five most used criteria to quantify the minimum spatial separation between the object points before their PSFs become unresolvable. They all differ by a **multiplication factor *k*** that quantifies the PSFs' spatial separation in terms of the wavelength-aperture product. The figure also indicates that one cannot define spatial resolution without involving the term contrast. For instance, the most popular criterion by Rayleigh states that two identical point objects will be distinct as long as the difference between the two irradiance maxima and the minimum in between them is not smaller than 26.5 %. Imaging detectors and the human visual system can easily distinguish such an irradiance contrast, provided that those maxima and minima are above their own threshold. That is why other scholars have provided smaller values for *k*.

Strictly speaking, most perfect point sources could still be observable at a slightly smaller separation. This led to the development of other two-point spatial resolution criteria (see Figure 10), many of which were proposed after considering the geometry of the PSF. Figure 10 illustrates that all these criteria can be written in a very general form. One just has to replace the number '1.22' from equations <14>, <15> or <16> by a **multiplication factor *k***. The difference between these criteria then boils down to a different value for *k*. The development of various measures to quantify spatial resolution notwithstanding, Rayleigh gave a very acceptable and general condition that is frequently relied on in the imaging industry. Now, how can we use the dimensions of the Airy disc and this Rayleigh criterion to come up with a statement of spatial resolving power in LP/mm?

3.3 LP/mm quantification

The Airy disc radius can thus be used as an approximate measure of the smallest spatial detail that an image theoretically can contain. An *f*/2.8 imaging system that uses mainly visible light (i.e. a central wavelength of 550 nm) produces Airy discs with radii of 1.9 µm. Using Rayleigh's criterion, Δx_{min} or the absolute minimum spatial resolution of an image equals, therefore, 1.9 µm. Since we know that spatial resolving power is the latter value's reciprocal, this setup features a maximum theoretical spatial resolving power of 526 LP/mm.

$$RP_{spatial} = 1 \text{ LP} / 0.0019 \text{ mm} = 526 \text{ LP/mm}$$

More values are given in Table 2. If we were to use another spatial resolution criterion, like the one from Sparrow, we would arrive at higher spatial resolving power values. Whereas Rayleigh states k = 1.22, Sparrow defined k to be 0.95. In other words, Sparrow said that two object points can be much closer together than the Rayleigh criterion before they are spatially unresolvable. How close? Until their Airy discs yield a cumulative irradiance distribution without any contrast between the peaks (see Figure 10). For an *f*/2.8 aperture and 550 nm light, this means a separation of 1.46 µm, equalling 667 LP/mm (i.e. a more than 20 % increase compared to the 526 LP/mm according to the Rayleigh criterion):

$$\Delta x_{min} = 0.95 * 0.000550 \text{ mm} * 2.8 = 0.0015 \text{ mm}$$
$$RP_{spatial} = 1 \text{ LP} / 0.0015 \text{ mm} = 667 \text{ LP/mm}.$$

Again, it is imperative to understand that real photographic lenses can never obtain these spatial resolving power values, simply because they always feature a varying amount of aberrations which results in image spots that are fuzzier and more irregular than the Airy pattern (see Figure 11). Only at small apertures, a lens might approach a perfect lens (because smaller apertures reduce the influence of specific aberrations). But even then, imperfect focus blurs an image spot considerably, so that the practical PSF of an imaging lens strongly deviates from (and exceeds!) this ideal diffraction-limited Airy pattern. To indicate that every object point corresponds to a blurry spot in image space due to the combined effect of diffraction, aberrations and focus, the field of photography has coined the quantifiable terms **blur circle** and **circle of confusion**.

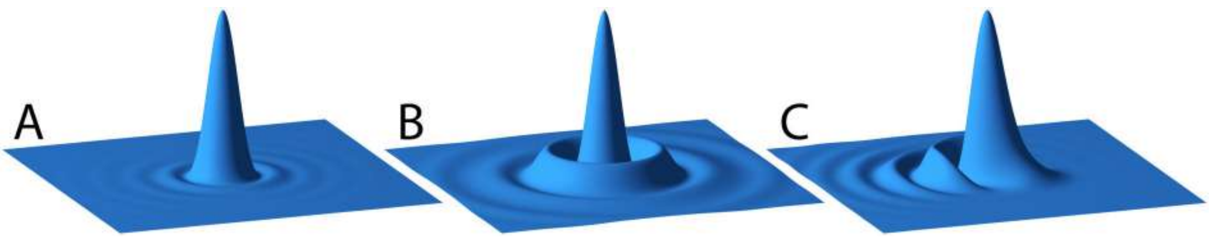


Figure 11 Inset A displays the three-dimensional PSF of a perfect, aberration-free lens. B and C depict the PSF for a lens with spherical aberration and coma, respectively. All plots have their irradiance normalised to their maximum.

4 Combining diffraction and geometry

4.1 Rayleigh in object space

Despite being purely theoretical, these Rayleigh-defined numbers can provide useful insight into the smallest objects one could spot from a remote vantage point. To do so, we have to combine some of the primary geometrical relationships with the diffraction-limited nature of electromagnetic radiation.

The Rayleigh-based computations of the previous section expressed the minimum spatial resolution Δx_{min} in image space. To state the same quantity in scene-specific units, we need to resort to the magnification factor. As explained in part 1, image scale is computed as the ratio of focal length to object distance (f'/s), whereas the scale factor or magnification m is its reciprocal (see equation <6>). Mathematically, the combination of these elements is written as follows:

$$\Delta x_{\text{min}} = 1.22 \lambda f_{\text{number}} \frac{s}{f'} \text{ [mm] (for photo camera lenses)}$$ <17>

$$\Delta x_{\text{min}} = 1.22 \frac{\lambda f' s}{D f'} = 1.22 \frac{\lambda s}{D} \text{ [mm] (for optical imaging systems).}$$ <18>

These equations allow computing the smallest, theoretically possible spatial resolution of any image, irrespective of the imaging sensor, the intervening atmosphere, the contrast of the object, the aberrations of the lens (which are assumed zero), and any object or camera motion.

Note that from everything we have said so far, it should be clear that it does not make sense to use the common term '(very) high-resolution image' to refer to an image in which many scene details are visible. The term is a *contradictio in terminis* since an image with many spatial details features a small resolvable distance, and thus a small spatial resolution. The imaging system that creates such an image is characterised by a high spatial resolving power. Therefore, so-called 'high-resolution' images do not convey small spatial details, and are produced by devices with low spatial resolving abilities.

4.2 Thermal and spaceborne imagers work against you

To illustrate equations <17> and <18>, consider an airborne camera flown at 350 m using a 50 mm lens at *f*/8. The exact type of camera is not important, as we will compute the smallest possible resolvable distance based on the lens aperture and the electromagnetic radiation imaged. We now get:

λ = 550 nm (0.000550 mm)
f-number = 8
s = 350 m (350 000 mm)
f' = 50 mm
Δx_{min} = 1.22 * 0.000550 mm * 8 * (350 000 mm / 50 mm) = 38 mm.

So, circa 4 cm is the very best we can do in the utopic situation that the sensor is not limiting the spatial resolution of the image, while we also assume a static object and camera, an aberration-free lens, the object impeccably in focus, and no influence of the atmosphere. Now, let us put the same lens on a camera that captures thermal radiation at 10 500 nm or 10.5 µm:

λ = 10 500 nm (0.010500 mm)
f-number = 8
s = 350 m (350 000 mm)
f' = 50 mm
Δx_{min} = 1.22 * 0.010500 mm * 8 * (350 000 mm / 50 mm) = 717 mm.

This shows why thermal imagery always features a larger spatial resolution. The only way to decrease the spatial resolution of that kind of imagery is by increasing the aperture (to *f*/1.4 for instance), flying lower (e.g. 200 m) or using a longer focal length lens (e.g. 150 mm).

λ = 10 500 nm (0.010500 mm)	λ = 10 500 nm (0.010500 mm)	λ = 10 500 nm (0.010500 mm)
f-number = 1.4	*f*-number = 8	*f*-number = 8
s = 350 m (350 000 mm)	s = 200 m (200 000 mm)	s = 350 m (350 000 mm)
f' = 50 mm	f' = 50 mm	f' = 150 mm
Δx_{min} = 126 mm	Δx_{min} = 410 mm	Δx_{min} = 239 mm

Finally, let us consider the physical size *D* of the aperture that a satellite-based imager would need in order to deliver a standard colour photograph with a spatial resolution of 10 cm. For this, we assume an orbit altitude of 450 km and need to use equation <18>:

λ = 550 nm (0.000550 mm)
s = 450 km (450 000 000 mm)
Δx_{min} = 10 cm (100 mm)
D = 1.22 * 0.000550 mm * 450 000 000 mm / 100 mm = 3020 mm.

To minimise the length of the lens, the engineers could opt for an aperture of *f*/1.4 (because any larger *f*-number would yield a longer lens). Nevertheless, to reach an *f*/1.4 aperture with a lens that has a physical opening of circa 3 m, the lens still should have a focal length of 4.2 m.

focal length f' = diameter aperture D * *f*-number = 3020 mm * 1.4 = 4228 mm

Such a lens is not only massive; it is also very costly, exceptionally complicated to construct, and the satellite requirements for its deployment not trivial. For example: the largest high-quality optical lens known for civilian purposes has a diameter of 'only' 1.57 m. This lens belongs to the camera system of the Large Synoptic Survey Telescope. Such telescopes collect electromagnetic radiation mainly by reflection on large mirrors, after which a smaller lens can be used to project the collected radiation on the imaging sensor. Modern satellite-mounted imagers also rely on large reflecting telescopes instead of conventional camera-like lenses, because large mirrors are easier to construct. Let us illustrate their potential with one last example.

The camera of the classified American KH-11 KENNEN reconnaissance satellite features a telescope with an alleged 2.4 m-diameter mirror, watching Earth from an orbital altitude of circa 250 km. Equation <16> helps us to compute the angular limit of spatial resolution, while equation <3> can be used afterwards to express the spatial resolution of the resulting image:

λ = 550 nm (0.000550 mm)
D = 2.4 m (2400 mm)
s = 250 km (250 000 000 mm)
$\Delta\theta_{min}$ = 1.22 * 0.000550 mm / 2400 = 0.0002796 mrad
$\Delta x_{min} = \Delta\theta_{min} * s$ = 0.0002796 mrad * 250 000 000 mm = 70 mm.

A theoretical spatial resolution of 7 cm is awe-inspiring indeed, but consider the hardware that is needed for this. All these examples indicate why it is so difficult to get a spatial resolution from space that falls in the airborne range. Diffraction merely is working against you, and only a large aperture allows getting around it. On top of that, the atmosphere and speed of the satellite are not exactly in favour of spaceborne imaging either. In short: capturing images from space is an entirely different ballgame from acquiring them within the Earth's atmosphere, dramatically influencing the hard- and software designs. That is why reading a newspaper or spotting pottery shards from space currently still belong to science-fiction stories, even for orbital espionage technology.

4.3 Achieving a balance between two limits

From equation <10> in part 1, we know that the GSD should be at least three times as small as the smallest spatial distance we want to resolve in the image. For the spy satellite setup, this would mean a GSD of 2.3 cm or smaller. Using equation <10> as the connection, we now can combine the geometrical view (i.e. equation <5>) with diffraction theory (i.e. equation <18>):

$$3\frac{sp}{f'} = 1.22\frac{\lambda s}{D} \quad \text{<19>}$$

Figure 12 graphically translates equation <19>. Both clearly express the most fundamental ways to reduce the spatial resolution of an image (i.e. increase image details), either by:

- improving the limit imposed by detector sampling (left side of the equation), achieved by:
  - getting closer to the subject (*s*);
  - using a detector with a smaller photosite pitch (*p*);
  - applying a longer focal length lens (*f'*);
- improving the limit imposed by optical diffraction (right side of the equation), achieved by:
  - capturing electromagnetic radiation with a shorter wavelength (*λ*);
  - getting closer to the subject (*s*);
  - using a bigger lens aperture (*D*);

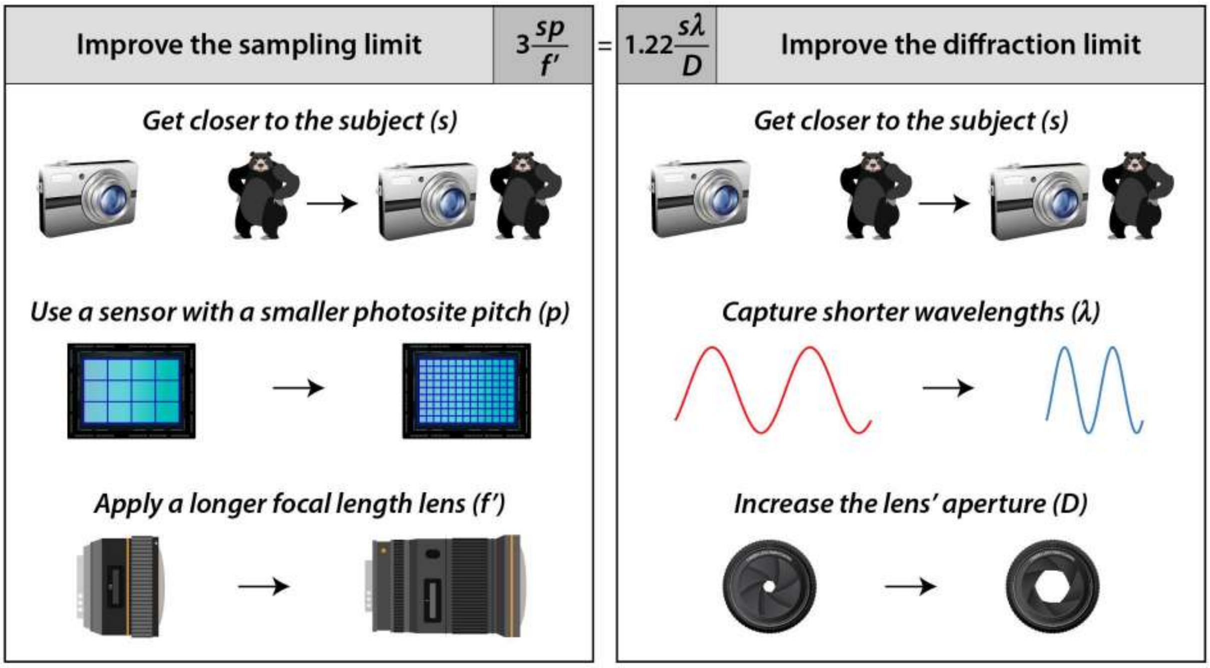


Figure 12 Achieving a smaller spatial resolution is possible via three geometry-related parameters (i.e. those defining the detector sampling limits) and three variables that determine the extent of optical diffraction.

The spatial resolving power limits imposed by the image sensor and optics thus need to be balanced for best spatial resolution performance. With equation <19>, we can now calculate the detector pitch *p* that an imager on the above-mentioned civilian satellite needs to yield this 10 cm spatial resolution:

s = 450 km (450 000 000 mm) → can be left out, because it occurs on both sides of equation <19>
f' = 4228 mm
λ = 550 nm (0.000550 mm)
D = 3020 mm
p = (1.22 * 0.000550 mm * 4228 mm) / (3 * 3020 mm) = 0.00031 mm = 0.31 µm.

Such a 0.31 µm detector pitch is – at least known from civilian systems – currently unrealistic. The image sensor carried by the WorldView-2 satellite features an 8 µm detector pitch. State-of-the-art image sensors used in very high megapixel phone cameras sport detector pitches of around 0.8 µm, but these suffer from poor performance in low-illumination conditions (of which satellite imaging is undoubtedly a good example). So assuming a three times higher and more realistic 1.0 µm detector pitch, equation <19> and Figure 12 illustrate that the same image spatial resolution can be achieved with a flying height that is circa three times lower (i.e. about 140 km). Since this alteration also influences the optical right-side of equation <19>, it has the positive effect that the aperture diameter can be reduced to about 940 mm.

4.4 Detector pitch-related diffraction threshold

In the first part of this entry on spatial resolution, we argued that digitising a line pair (or any feature of a given size) with three pixels seems more appropriate than the two pixels per line pair given by the Nyquist–Shannon sampling theorem (this is also reflected in equation <19>). Since we know from the Rayleigh criterion that Δx_{min} equals the radius of the Airy disc, it follows that the best 'match' between sensor characteristics and the optics is achieved when the detector pitch p equals one-third of the Airy disc radius. In other words: three pixels suffice to resolve the Airy disc radius entirely. The reasoning then goes that above that threshold, the optics diffraction limitation kicks in. So digitising the radius of the PSF's central part with more than three pixels does not improve the final spatial resolution of the image because the detector only resolves diffraction blur at that point.

However, photographic tests show that the visual impact of optical diffraction starts already earlier, somewhere between two and three times the detector pitch. Because it is impossible to give one definite number for all cameras and lenses, this three-pixel threshold is often redefined as twice Rayleigh's k factor of 1.22:

$$r_{\text{Airy\_max}} = 2.44p \ [\mu\text{m}] \qquad \text{<20>}$$

Criterion <20> quantifies the **detector pitch diffraction threshold**. At that threshold, the optics' diffraction and detector sampling rate are <u>visually</u> in balance. Figure 9 illustrates this limit for a 4 µm detector pitch (commonly found amongst digital photographic cameras):

4 µm detector pitch diffraction threshold = 2.44 * 4 µm = 9.8 µm.

Above that value, optical diffraction *likely* deteriorates the image details, because the PSFs are simply too big regarding the detector pitch. Replacing and reshuffling some terms in equation <20> allows expressing the maximum *f*-number that can be used given this threshold:

$$1.22\lambda f_{\text{number\_max}} = 2.44p \rightarrow f_{\text{number\_max}} = \frac{2.44p}{1.22\lambda} = \frac{2p}{\lambda} \qquad \text{<21>}$$

This *f*-number is denoted the **diffraction-limited aperture**. When dealing with visible radiation, 700 nm should be used for λ since this is the upper sensitivity of any standard digital photo camera and diffraction is biggest at this wavelength. This indicates that optics-induced blur starts to dominate around and after *f*/11 in the visible range for most modern still cameras (see also Figure 9):

$f_{\text{number\_max}}$ = 2 * 4 µm / 0.7 µm = 11.4.

Aperture *f*/11 is, therefore, the lens opening at which a camera with a 4 µm detector pitch becomes diffraction-limited. At smaller apertures like *f*/16, *f*/22 or even *f*/32, the imaging sensor simply out-resolves the camera optics, hence limiting the system's total spatial resolving power and yielding a fuzzier image (Figure 13B). Note that the amount of optical diffraction is always determined by the optics; the size of the detector pitch just determines when and how well this limitation will be spatially resolved. For those reasons, 'pixel peepers' use a factor of 2 instead of 2.44 in Equation <20>, which in turn yields a factor of 1.64 in Equation <21>.

Equation <21> also teaches us that this diffraction threshold is lower for sensors with a smaller detector pitch. Smartphones commonly feature a 1.4 µm image sensor pitch, which means that optics-induced blur will deteriorate image details for apertures smaller than *f*/4 (see Figure 9):

$$f_{number\_max} = 2 * 1.4\ \mu m / 0.7\ \mu m = 4.$$

[Although an in-depth treatment is out of scope here, note that smaller apertures increase the depth of field (see Figure 13A). This relationship is a double-edge sword with significant consequences. Balancing diffraction versus depth of field is, for instance, vital when determining the ideal aperture for image-based three-dimensional modelling.]

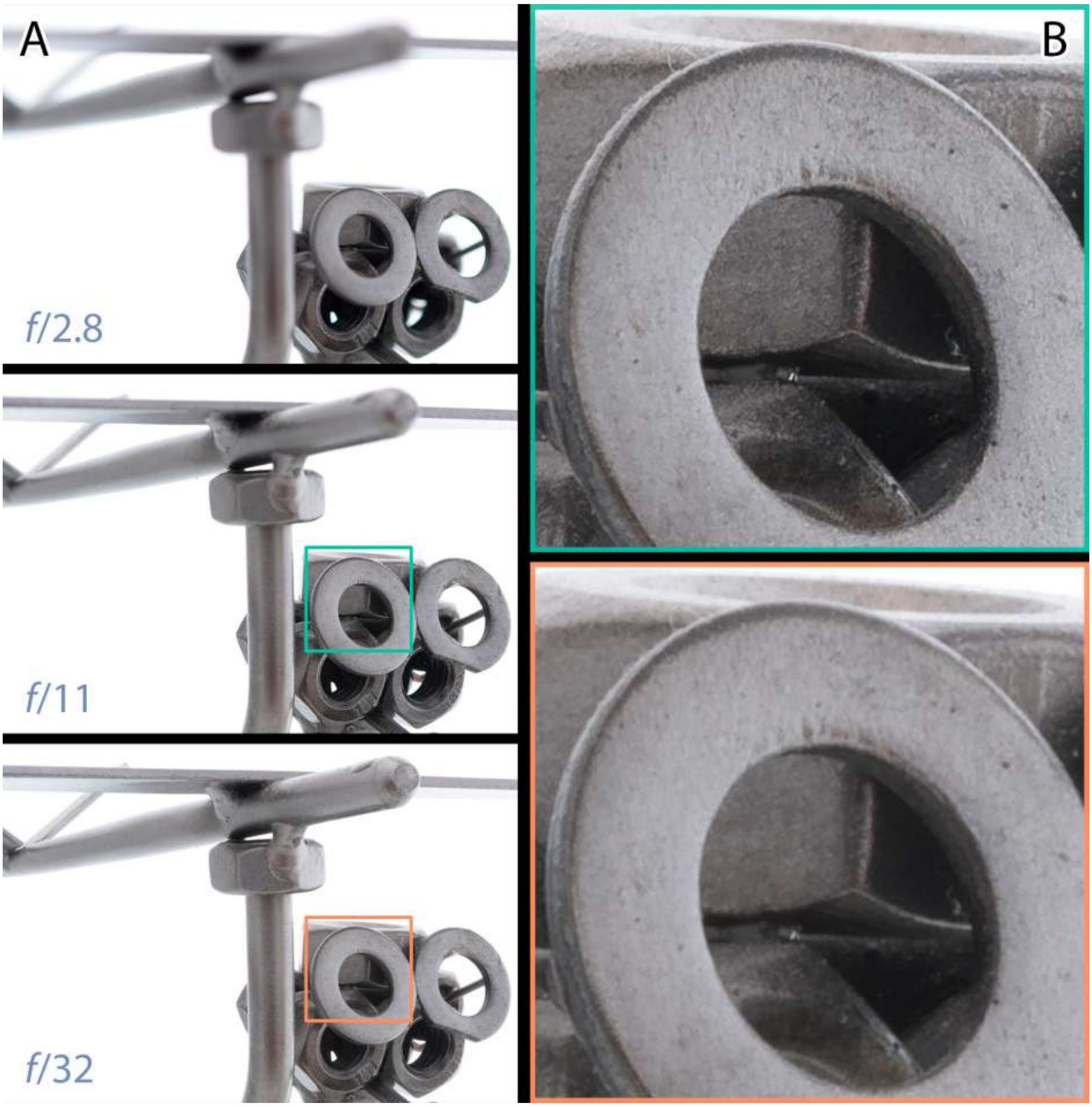


Figure 13 The insets of column A illustrate the influence of aperture on depth of field (check the wings and tail of the glider held by the figurine), while the insets of column B reveal how diffraction of small apertures blurs image details.

The reverse of equation <20> is also true: two points may not be resolvable when the detector pitch is too big. For example: there are simply insufficient samples generated by 4 µm photosites to capture the radii of *f*/2.8 Airy discs. Although this issue can be remedied with smaller photosites, it will lower the detector pitch diffraction threshold in turn. That is why Figure 12 treated both sides of equation <19> as imposed 'limits', and a well-designed imaging system must strike a balance between them.

Here, we also enter some fascinating territory. If we would like to quantify the limitation imposed by the detector sampling, should we:

- merely use the inverse of equation <20>, which states the condition when optical diffraction is expected to worsen the image details visually:

$$p_{\text{ideal}} = \frac{1}{2.44} r_{\text{Airy}} = 0.41 r_{\text{Airy}} \ [\mu\text{m}], \qquad <22>$$

- or use the inverse of the number of pixels that are needed to resolve a feature (i.e. three, yielding 1/3 or 0.33), in agreement with equations <10> and <19>:

$$p_{\text{ideal}} = \frac{1}{3} r_{\text{Airy}} = 0.33 r_{\text{Airy}} \ [\mu\text{m}] \qquad <23>$$

The difference between the two highlights one of the major difficulties when assessing and talking about spatial resolving power: detecting is not recognising and vice versa. We can typically spatially detect before we can spatially resolve, and we usually must spatially resolve an object before we can identify it. Remember Figure 6 of part 1: a circular object of 50 cm diameter could be detected using a GSD of 25 cm (i.e. two pixels per given object), but a GSD of 16.7 cm or even 12.5 cm (i.e. three or four pixels per object) were needed to more or less resolve and identify it.

This is a fundamental distinction that often gets lost in the remote sensing and photographic literature, as is the fact that all quantifications up to now are theoretical and simplified! The real world is much more complicated; images include noise, intervening atmosphere and motion blur, while the final spatial image resolution also depends on the form and contrast of the scene objects. Some of those factors will be considered in the third and last entry on spatial resolution. That part will delve into the world of spatial frequencies, bar patterns and modulations, and illustrate how these concepts can characterise imaging systems in ways none of the previous equations was able to do.

That being said, there is still one important message I would like you to take home: if there is no need to apply tiny apertures, avoid them. For most aerial imaging situations with full format or smaller sensors, this means sticking to apertures equal or bigger than *f*/8 (i.e. *f*-numbers ≤ 8), simply because the image will otherwise suffer from unnecessary softening. On top of that, *f*/8 (together with *f*/5.6) is the aperture where most lenses optically perform at their best (their so-called 'sweet spot'). Finally, smaller apertures also reduce the shutter speed, making it easier for aircraft-induced motion blur to sneak in the image.

AARG Conversation No 4(2): Darja Grosman and Rog Palmer: 17 September 2018

This second conversation took place late one evening after our return to Ljubljana from Pula where we had been to visit Sara Popovic on her return from AARG in Venice. Sara was vocal about some Venice happenings and our conversation reflects on some of the Pula discussion. The main points of that three-way discussion about the future of AARG were noted to be:

- *Regardless of what AARG is about, we need to identify and (re)define its main direction(s):*
- *Does AARG need to be re-invented?*
- *Do we need to adapt to new fields? For example, technology as technology has taken over from archaeology but does this reflect the interests and work of members?*
- *Should AARG concentrate more on education now that Arcland is [almost] defunct?*

What follows includes some ideas about future directions for AARG and the need for educating 'general' archaeologists about the uses and values of aerial information but there are also a number of diversions and some fairly heavy editing that has removed large chunks.

Future directions for AARG?

DG – We're talking about this question of how AARG should question itself, reassess what it is about. And what would be its main directions. Whether we need to reinvent AARG or it just has to adapt some new fields and put then all together into a firm structure, or whatever you want to call it.

RP – Are there any new fields?

DG – Yes, the pushing in of technology in the last few years is predominant and is taking over our discussion of archaeology in general.

RP – It does come down to 'what is the membership doing?'. Now that EH people no longer come to AARG, there are no…. OK, Dave [Cowley] is beginning to formulate his national mapping programme [in Scotland]. Toby [Driver] I think is more or less following what EH are doing but nobody is quite sure what is going on in [continental] Europe. If anybody has started mapping areas it is probably going to be Martin [Gojda] – I've seen more mapping from him than anybody else. It doesn't mean to say they haven't been doing it because I know that Lidka [Żuk] has been doing some [in Poland].

But I think that the reason that Lidka didn't do her PhD area in Poland was because they haven't got any joined-together areas and she wanted to discuss movement and something she could picture rather than 'here is a long house, here is a long barrow, there's a lot of space in between'. So I don't think they've got a very cohesive picture.

DG – So apart from Austria, that Carnuntum thing. Maybe they have… We have to look at Martin Ferra, what he has been doing, because they haven't been mapping on a national basis, they've been mapping different sites, different things. Maybe Sicily has been mapped or partly mapped because of their work there. I don't know that. That's the second-biggest project. And the one they showed now, this little rather micro-regional thing … the monastery[1].

RP – We had some good ideas last night [talking with Sara in Pula]. Can you remember them? We talked about why AARG was started which was to discuss the problems and potentials of using aerial information: what do aerial photographs tell us about archaeology? And in Ashbee's words [*AARGnews* 28, 10-18], do we need to write a *new* archaeology based on the aerial evidence or can aerial information be adapted to the existing framework? I suppose then he was thinking about the fact that – early 1980s wasn't it – that aerial photography, and it was just photography then, had introduced a number of new categories of site. Henges, I think were unknown before aerial. Not causewayed enclosures, but we added to them. Cursuses we added to. Probably the range of what may or may not be, or are likely to be, IA aerial enclosures and complexes. Field systems were known but we enlarged them and moved them into new territories.

So in a way the first option, does archaeology need to be rewritten, because we know so many more categories, may have been the one to go for. Except there were very few archaeologists using that data within the early AARG. And since.

DG – Yes, but if we go into this question of classification as an important tool, if you want to. Identifying similarities in form you must take in account what a diversity of landscape the continent brought into it. Of course, there are large areas that have similar environmental conditions and landuse practices, but there are other things that are completely different. And there, there is no classification. The lack of mapping things brings out the question of what are classifications that exist.

RP – I think the first thing is to ask whether and how classification is likely to help us, because, as one of the inventors or first users of it in the aerial world, I'm not sure now whether it offers much.

DG – Yes, but let me put it this way: I think that similar forms that you have named or classified or identified – or if you want to, not further than 'identified'. We have, in a different environment, in different forms, different shapes if you want to, because they are standing here on this side as well, or in the Mediterranean world. I feel that maybe we should accept that archaeology or mapped archaeology from aerial photography does need to give a result without (of course you have archaeological knowledge) but without initial comparison with something else. And it must enable studies without really having all the other information, because for a lot of places, it's the only one that gives, or that gives us, information. On the second level then, it's only the time for comparative analysis. That's how I understand it.

RP – Yes, it shouldn't be written off completely, but I know that in local areas, in parts of Cambridgeshire and Bedfordshire, which is a small bundle west of Cambridge, let's say, there are very distinctive middle IA enclosure shapes that have been excavated, so we know the

[1] Doneus, M. and Kühteiber, T., 2013. Airborne laser scanning and archaeological interpretation – bringing back the people, in R.S. Opitz and D.C. Cowley, (ed), *Interpreting Archaeological Topography: 3D data, visualisation and observation*. Oxford: Oxbow. 32-50.

date of them. They have a characteristic plan form so you can go through mapping and pick out things like that. OK, it's not doing it by itself [ie from just the aerial evidence], but doing it by itself might bring out that category as a question, 'what are these?' which you can put in a list and ask, 'we want to know what these are'. That's one of the tests, or the first question once you've identified your significant types. Then you can ask for more evidence about them that may come from resuce now. I know a lot of the middle IA things have been rescue dug. OK, I'm looking at my small patch, my 'field in Cambridgeshire' as Dave [Cowley] describes it, but it [use of classification] can certainly be extended over the rest of Britain and maybe parts of Europe where you've got a similar density of photographic information.

Relevant diversion about available photographs and mapping in various countries
DG – We don't have that bad photographic coverage, it's quite acceptable up to the Second World War. The problem is, how much it is used and how far you need to pressure for accessibility, but opening therefore the necessity to have a geoportal open before you even consider joining the European Union gives you the basic view of how much is already publicly accessible. One can start from that – eh?

RP – What I was going to say was that it's not the quantity of photographic information, it's the work that's been done on those photographs extracting the archaeological information.

DG – Yes. Honestly, there's been done half a percent, maybe. If I'm very optimistic. If I look at the southern part of Europe. I'm not going to talk about Poland or Czech, and even in Czech, it's areas like Bohemia and not the rest of the country for instance.

RP – I know that Poland uses the archive (Geoportal) but I've no idea what Martin [Gojda] or Czech does with it, or whether they are entirely reliant on their own photographs.

DG – Zoltan [Czajlik – Hungary] certainly works on both, on verticals that are existing and on him flying. Zoltan is now, since he has Laci [Rupnik] working on mapping as well, even though they don't map systematically. It's problem-orientated because it's university. They cover a part of Romania as well.

RP – Carmen [Miu] has done virtually no mapping [in Romania]. Ioana [Oltean] has done bits and has probably mapped more of Romania than any local. I've never seen all that much archaeological information on Carmen's photographs or when I've been flying with her, any enclosure type things that Ioana was getting. Last year when we went flying, she was in charge of where we went and there were a couple of times when I photographed what I thought was potentially archaeological as we went past which still looked fairly genuine when I got it home.

DG – But this is another problem that exists. Looking at a landscape in which you don't identify things and you are afraid of recording or using time to actually record things that you don't understand right away. It's about understanding that there's something different, that there's potential there, and that you should record it while you're learning or while you're getting acquainted with certain things. Otherwise the finding is going to become a problem, isn't it?

RP – Yes, sure. And the way I've always looked at taking aerial photographs is that you don't spend too much time thinking about it in the aeroplane, you photograph it and sort it out when you get home. I remember with Roger Featherstone once [aerial photographer with RCHME] going round and round a field – endless times. He was trying to work out whether it was all geology or whether there was archaeology among it. I said, "Take a picture and sort it out later" but he didn't want to do that.

DG – Yes, but you have to be firm enough to photograph, or to stop and photograph, things that you think might not be: they might be. It's not 'I'm trying to find it because I'm not sure what it is. I'm just trying to understand whether there is something I could find and a lot of people calculate or balance this thing whether I should photograph it and it is not or whether I should stay just with the things I know.' And that's where the selection gets 50% down, especially in the beginning.

RP – I know this happened with Cambridge [CUCAP] because there are virtually no photographs there with that sort of question mark. It's either archaeology or it hasn't been photographed. This is why St J[oseph] got lots of good sites, because he missed out all the stuff he didn't understand. It's a bit like the way Helen [Winton, HE] said at one time about the National Mapping Programme, "If in doubt, leave it out" if you're not sure about it.

DG – That's not the best approach.

RP – I don't believe in it and I had a category of 'uncertain archaeology' – it might be archaeological, it might not be.

DG – So there are still a small number, or small amount, of areas on the continent you can say have been mapped and you certainly have even less that has used this mapping.

More AARG ideas

RP – Didn't we, at the café, also talk about the education side? What I wrote down as an extra for what we said – that technology has taken over from archaeology – does this actually reflect the interest or the work of members? AARG needs to, in a way, be driven by its membership to question what we're doing and look at what we think we ought to be doing.

DG – Can't we stay within the framework of both things? Looking at what people are doing and yet having a general goal to how these things could be put together?

RP – Yes, because aerial-related technology will probably slow down soon, or it may do. What have we got? We've got drones, we've got lidar, we've got auto-extraction.... At the moment there's a lot of technology going on and everybody is trying to grab it and use it first because then their name will be at the top of the heap. But it's still using the technology as technology rather than bringing us anything that is useful.

DG – Photography has been, at the moment, not used for mapping, it's been used for 3D. That's why the technology in the archaeological sense is narrowing into a field when we actually don't know how to use it properly. We need some time, I guess, to deal with 3D.

RP – I think we see a lot of 3D models because they are sexier than the orthophotos that are produced at the same time.

DG – Because if we use real time records, which is a picture, draped on a lidar model we'd have a 3D model. Or we'd have a 3D model from which the height differences or the 3D properties are derived. Amen.

RP – The main question is why do we need them and has any useful explanation come from it?

DG – Has it really improved any of understanding or interpretation actually? This is where surface morphology is something that is not taught to archaeologists.

RP – That's what I would think of as looking at bumps, isn't it?

DG – Yes. If you're not properly taught things like that, or at least being made aware of it, then you think of it as something, I don't know what.

RP – It was never…. OK, I'm thinking of the pre-lidar days now. The surface topography, if you want to call it that, is what the Royal Commission surveyors excelled at. They could do it like nobody else could and go into a [apparently] flat field and find all the bumps and then make sense of them.

DG – yes, because it's a lot of work.

[*There followed a diversion into the pros and cons of analytical field survey and what can be shown at different map scales and just how much archaeological content some maps have, or do not have, and then to the needs for mapping of AP information.*]

Teaching and the acceptance of AP information

DG – It's not that I want to have always archaeology mapped out. We don't have archaeological maps at all, you know, apart from this or this or dots. Nothing is mapped out apart from bits and pieces. And all of these bits and pieces are not even on a stretches that are motorways or things like that because none of this [mapping in advance of development] was done.

RP – It's to be expected because a lot of this is going to come from mapping done for a purpose other than building up a national record as could be university research projects: Sara's PhD [Hvar], my non-PhD [Wessex]. In my case it was, my interest, my background, from outside the university, that said "I know about aerial information, this is what I want to do.". You will not find, I don't think in any university in the UK, a teacher who is … I was going to say 'competent' to tell any student what to do or even to have the knowledge that they could suggest this to a student as a possible way of doing a research project. Because none of the teachers – OK, Ioana [Oltean at Exeter] – none of the other teachers have a background of aerial use. All the students follow, to some extent, what their teachers' expertise is in their research projects. So if you haven't got teachers who have been working with this stuff – and certainly in Britain we lack them – you're not likely to get the students following. Wlodek [Rączkowski at Poznan] has done quite well with his, Martin [Godja at Pilsen] has done very well with his.

RP – Cambridge have me for two hours in their three years because I'm there. Every other university has one of the teachers who is given the job of 'you do methods this year' and it [aerial work] is probably a tiny part and I imagine is at the level of 'aerial photography discovers sites' because that's how it's been told in a lot of text books.

DG – But, yes, never mind. If you don't have teaching and teachers where do then, the people that do this work come from?

RP – It's a job.

DG – Which means that the whole thing starts by you having no idea what it is. That you actually learned this thing by entering a job.

RP – Yes.

DG – OK, so the whole stuff that we're doing on the continent actually doesn't bring us to people who are going to do this job.

RP – Well, Lukasz [Banaszek] has just got a job with Dave [Cowley at HES].

DG – If he had stayed in Poland, he wouldn't get a job [involved with aerial information]. OK, so we're there. We are producing, or we are teaching, something that never gets down to the jobs because there are no jobs of that sort. Which means that there's something different or something lacking in the system of what sort of jobs are there in archaeology on the continent. It is contrary to you [UK]. When you say you don't teach it, you give them some information, or the first instrument, the first push at the university, then it's a job in which you'll learn the rest of it. We'll never have that on the continent.

How things 'work' in Slovenia

RP – We're back to the differences between Britain and the continent, with the acceptance of AP information. At the heritage level, the Sites and Monuments Record, they expect to have a layer of, for want of a better word, crop marked aerial information. You said earlier that, that your lot don't. I'm not quite sure what happens in Poland with their stuff. And does Martin send his maps up to the heritage people?

DG – Probably not because nobody actually does anything that would be called a programme of air for flying or transforming photographs doing maps out of them and things like that that would end in an office. If I was digging I have to do it [provide a report].

RP – Yes, but that's a small couple of fields, isn't it.

DG – I'm not talking now about the size of it. I'm talking to this thing. Nobody asks you for, and you don't give it because it's your research bit this thing. You have to do it. Even if it's your research bit, you have to put a report in. If you're making this little hole, you could do a whole landscape, mapped in aerial archaeology. Nobody's going to ask you to give it to them and you're certainly not going to give it to offer it if nobody asks. Even if they wouldn't ask, you wouldn't offer it because people like to sit on their own information. It's usually easier and it's less criticized. So we're talking about two completely different things. We're incompatible in this sense.

RP – So okay, so one point. Where AARG may be able to enlighten people – I won't say educate – is with the heritage people of Europe to show that the uses that interpretation of aerial photographs might bring to their Sites and Monuments Record and how that can be useful to the planning process. There may be the people that need … I'll stick to enlightenment rather than teaching. They need to be shown.

DG – Enlightenment is a good word.

RP – I find good words sometimes! If that's where the blockage is, if it's them that aren't necessarily saying there is no information on aerial photos but they are barely aware that they exist, let alone what might be on them. Then that is maybe a target body to aim for with course of some sort. We tried it with the Polish inspectors way back, one of the Leszno courses in 1998. But they started off anti-aerial photos anyway and I don't think it changed any of them. So, yes, it's not going to be easy. Or maybe there's a heritage person that says, yes this is really great, we're going to do it. Let's say Slovenia, if your heritage is managed by local areas, if one starts doing it maybe all the rest will want to do it.

DG – Yes, but only one, only one, has to start it not look at it as something that is maybe going to give me an illustration. But it can give me a result, an archaeological result, because I've worked on it archaeologically, I've studied it and then produced an information layer that is a map that gives the possibility to me, to argue what it is from my point of view, and others to use it and compare it with their results.

RP – Yes, ok, so what we've done is identify the weakness in a system, the system of heritage management in this country for which AARG may be fairly well equipped, to even give a one-day seminar. What actually works in Britain is Friday afternoon seminars, because then everybody can go home early if you don't give them a full afternoon. Really. And more people come to that because they can skive off work. But you can't sit and steam because they don't know, if nobody's told them.

DG – They *do* know. There's a difference.

RP – But do they know, rather than you jumping up and down, saying, you're not paying any attention. With more gentle approach that might start off with almost the idea we had the other day. You start off with what is known, which is their record at the moment, and say that if you look at aerial photographs – and you have your series of verticals even without any that you've taken – and if you look at the aerial photos for this particular area you *will* get more information. Even if a site is not showing you will get more information. But if archaeological information *is* showing then it can be added to your maps as a warning that this might indicate something that is going to cause trouble when you build a road or extend a graveyard or something. Let them see for themselves what is there. We'd need to pre-select an area where there are going to be results, I suppose.

DG – It's not even difficult to get into because, remember Gašper [Rutar: a Slovene student on our course in Serbia in 2011]? Well Gašper is the person that should be doing that. Not as an air photo interpreter, he's the curator of the archive of all this, so called, mapped information that we have that comes in from all sorts of work in the field including things like maybe there's something on the aerial photographs.

RP – But, if you like, at this early stage it probably doesn't really matter that you've got a proper – if that's the right word – proper photo interpreter because I probably let the heritage people do it themselves after a bit of instruction, and then they would begin to learn what was good and bad information. If you gave them a set of six photos of different dates, and let them find stuff on them, sketch it on to a map, or maybe the photos are a layer in the GIS and they can draw it in the right place. Then the teacher goes round and says, "OK, what's this? Why did you draw this?". So you start letting them learn from their experience, from looking at the photos, and their mistakes or not. It's a way of teaching. Nowadays, we don't need all the computer stuff that we were doing. OK, they need an idea that a dark green line on a photo at a certain time of year may be a hole in the ground. They need to know what they're looking at but we could actually train them up in a few days to be good enough to add this information to a layer of 'possible stuff' on a heritage map, I would have thought.

DG – I'm looking at what the response would be. We know all of that. It doesn't matter that it is not done, that it is not exercised. It isn't something that is perfectly natural, to go with this stuff, you know? The Americans use the word 'attitude' don't they.

RP – What, to people's approach to things?

DG – Yes.

RP – Yes, because I suppose, they haven't been introduced to the potential of these things.

DG – Thank you, they're all my students.

RP – Are they?

DG – Yes, all of them.

RP – OK, they have then, but somewhere they've forgotten a lot.

DG – That's my frustration.

RP – Yeah, so it should be I think.

DG – It is, it's horrible.

RP – So they'll be easy to teach and then they go away and forget it.
DG – Again.

RP – Yes, like they have already. That's quite worrying, more worrying. So what you're saying is that the people in the heritage organisations were all your students at some time.

DG – All of them. From the teachers at the university [of Ljubljana] from the oldest downwards, there's only one Department of Archaeology in this country. Nobody is sent somewhere else.

RP – Soooo.

DG – Ha ha, I've got you now.

RP – You've got me now, but OK, the first question is to ask whether … this came up earlier… about a 25 year old being brave enough to say 'bollocks' to a 45 year old. Presumably they've gone into junior positions in an organisation that has a list of things that it does and doesn't do. They haven't shaken the boat much, so we need to get to the top people, not the actual people who do the work. Like Otto [Braasch] always used to say, "Take the professors flying and the students will go later.". It's going to be like the Ordnance Survey, the heritage people will have the standard list of thing they record and if aerial information isn't there then it doesn't come in and your lot haven't got the experience, maybe, to say, "But, but, but Darja taught us that this was a good thing.".

DG – I don't know exactly how it works in your heritage offices, but this system is like that. You have a main body, it's a National Institute for Bla, bla, bla, and then it has seven regional bits. In the seven regional bits you have one person who is called Conservator, or whatever you call it, is an archaeologist who does all the legal side of it. What I want to be done archaeologically before we give you the permission to build and bla, bla, bla. And then you have, in this department, people who then are the 'fire brigade', who do that work in the field if it is not delegated outwards, because it's too big, to the private companies. This is the so-called CPA (Centre for Preventive Archaeology) they don't do *anything* in advance, they're exclusively rescue people. So they are a hanging body there, of archaeologists, who do fieldwork. And then you have, within this CPA, someone, or a few people, who deal with the sites and monuments record, but with the archive.

RP – Feedback what they found, you mean? Or look in the SMR as they are digging?

DG – No, no. Taking everything in when it comes as a report from somewhere. OK, there is geophysics sometimes done, there is lidar done because Micho sits there. There's nothing done on the aerial photographs.

RP – OK, so your conservator, the one person that is employed to look after the …

DG – The record of the region? The regional ones don't have one that takes care. The record is cared in one place.

RP – So your regional conservator might say to the digging people, "There's a Roman villa where this road is going.".
DG – Yes.

RP – So they know that, ok. So it's up to him to warn a day in advance what these people might find. But you've also said that they've got …. What I think I wanted to say was that the flaw in that process is that there is no pre-excavation planning. You know, like the work that I did. And in the UK that is an expected part of the process.

DG – The pre-excavation part of the planning exists only on the big development projects, similar to like it was on the motorways, not on a single site.

RP – But it still wouldn't include looking at the aerial photographs?

DG – No, it doesn't. Because they don't think it is, as you usually have this situation, that the information should be believed in. We have to check it on the ground if we want to say that it's really archaeology, and because there are not people employed, or even in contract, to do that. So nobody goes in that direction. You said it yourself, the job is then, at the beginning teaching them.

RP – Do you think the diggers would benefit from having an AP plan if they are working in that sort of way?

DG – Of course it is. Sometimes the archaeologist, the one who decides what is supposed to be done is going to say, "OK, you fieldwalk that thing.". You know, things like that. But it's never AP work that would be done as well.

RP – Yes, OK. That's … a bit worrying.

DG – Yes, it is a bit worrying.

RP – But if there's nobody capable of doing it, you're going round in a circle, aren't you. Except that your students, presumably, should be capable of doing it.

DG – They could do it, but it is not something that this whole machinery would incorporate. They don't want to.

RP – So my question would be, how much more might that add?

DG – I think, a lot. If you take just the little bit of open land that exists here. With a bit of hard work, you could get there. It's just not obvious. And the moment it's not so obvious that they say, "We might believe it."

RP – What you've just said means that you need specialist interpretation – interpreters – rather than the curators.

DG – I understand that. I'd say that maybe I have given them enough information during their studies that they would know that it is bringing something. You need to have enough room, and enough start time, to produce a result that's going to convince the rest of them that this is something that the system should introduce.

RP – So we were lucky with the way the planning law changed because that's what it all revolves around. Without the planning law [PPG 16] in 1990 or thereabouts, there would not be commercial archaeology in Britain. The planning law said that the developer pays for the archaeology (I think).

DG – Here it's exactly the same.

RP – So the counties, which are like your seven 'bits', agreed – and I think there's a nation-wide agreement – on the way things are done. That you have your … before any excavation is done, you have your desk-top assessment. And that does vary between counties. Some of them will ask us [Air Photo Services] to do things – or if you like, the professionals to do things. The AP 'goodness' varies from county to county. This is where the drinking came in when we started, convincing people that they need it done properly because otherwise you get the people from big units going into Swindon [HE public search room], being given a heap of photos and looking at them in half a day or less and saying, "We have done the aerial photographs." because that was the requirement by the county, and no one knows any better.

DG – OK, but the private [companies] don't have this bit at all, even if they say we're going to look at the photographs. The photographs that lie with us in a place where you have to pay for it. That's the next problem. And the second thing is, we don't have professionals, like yours, like you and Chris [Cox] that can do it. The desk assessment isn't really a desk assessment. It's a … the rules that this regional archaeologist heritage office gives the developer in terms of what of archaeology should be done. There's never AP work involved, because we don't have firms like yours – they don't exist.

RP – You don't need them if all these curators have been trained to do it themselves.

DG – Oh, no. No, no. They don't do *any* archaeology. And the rest of the archaeologists that are in this CPA part, they are the field segment. They first of all dig, they do geophysics, write reports and things like that.

RP – So are they the people to persuade that they need to include photo interpretation amongst their work?

DG – I've been trying to do this for more than 20 years, but it doesn't work.

RP – So why doesn't it work?

DG – I don't know.

RP – We could have got the same, I suppose, from the county archaeologists. They could all have said no [to the specialists] this lot can do it for nothing. They're going to find it on the ground anyway.

DG – And you have 90 years of tradition in seeing published aerial photographs as a result and things like that.

RP – Yes, We believe them.

DG – We don't, that's the problem.

RP – I'm not sure how to get round that. And it would be interesting in a way, given that …

DG – And we're not the only example, you know.

…and a diversion into Germany
RP – I was about to spread out to Germany and wonder what happens there because Otto *must* have convinced some people in similar positions – the heritage people – that air photos offer information. So it would be interesting to know what, if anything, is done

DG – What is done, has been done. Remember you went with Johanna [Dreßler] to Fassbinder [in Munich]. Why did she choose that library? I'm certain that Joerg didn't say no, we're not going to give it to you.

RP – No, he didn't, he was welcoming her to use them.

DG – If you look today in Germany, who is flying?

RP – Nobody, probably. But it would be difficult to do flying. Johanna got from a lot of the professors that she tried to get to supervise her, "Hasn't Otto done everything already?". So Germany probably thinks it's done. If Otto Junior came along and asked to go flying, he'd probably be told by most places that it's been finished. There are, if you look at the distribution map, which I think came from one of Otto's picture books, there's a distribution map of his flying in Germany. There are some states where he obviously only went once, some states where he's never been. He flew enough years to photograph the same sites several years to allow for crop rotation, I imagine … this that and the other. So he will have seen a lot but it's [Germany] is certainly not done. Nor is it mapped, so there's an archive.

DG – Which means that they have a system problem as well. Even though they have the Landesampt Denkmarkflegal in Munich, a nice archive of verticals and obliques, they have the same problem as we have.

RP – Yes, they're not used, and yet Johanna said that in Germany there is, I think, no concept of private companies. Everything, I think – I may be wrong in this – everything is linked to the state organisations. So the rescue diggers are employed but she couldn't start an Air Photo Services in Germany.

DG – As you couldn't start it here [Slovenia] because you couldn't sell it [the service] if you wanted to.

…and England
RP – Like I said, we [APS] were lucky because of the planning law and because we knew people in the local [heritage] organisations. Really, that's what got us going. And I suppose, the fact that the Cambridge Archaeological Unit and the County Unit, who were the ones that we certainly did a lot of early work for …
DG – Where do the County Units belong? To the Counties or to the Royal…?

RP – They were employed by the County Council at that time. There is no longer a County Unit [in Cambridgeshire]. The County Unit went through …

DG – See, that's the first problem, because all of our regionals are employed by the main heritage office, the National Heritage Office or Institute. It's the regional division that is covering everything but it's all employed by the Heritage Office.

…and Italy, Belgium and a lot of other countries
DG – If you look at Italy. Let's say that Italy has, after 2000 somehow, through Siena and Grosseto, established some kind of acceptability. In the south, in Taviolere, as well as in the north in Tuscany and through Tuscany up in Pedro Bergamont, Po Valley and Bergamont and all that, and Arianna [Traviglia] doing her mess in Apulia or in Venice, whatever. But, the thing is, that you can't live off this. You don't have interpreters in Italy. Not in the Soprintendenza*,* it doesn't have this layer at all, doesn't work on any aerial photography, doesn't fly, doesn't do anything.

RP – Didn't Stefano [Campana] do a road scheme somewhere in north Italy?

DG – Yes, he did, Bergamont. He did it from his own – the money came from the builders... It didn't change anything, Bergamont. They didn't establish anything that didn't the central Rome approve and support and finance and I don't know what…and as I say, you don't have specialists that could do *this* sort of work. After all the years and all the results that were presented in 'total archaeology'. It starts with geophysics, field walking, bla, bla, bla, down to excavation. Lidar has moved in there: aerial not.

RP – But Stefano's drawings of what he calls 'total archaeology' include satellites and aerial…

DG – Ya, but it didn't go into, they might do some rescue thing as they did in Bergamont but that doesn't influence anything on, if you want to, county levels or whatever levels. In protective archaeology or in rescue archaeology in the heritage offices this [work on aerial photographs] is non-existent.

RP – OK, I don't know how to get round that.

DG – As I say, this is not – and if you think about the Germany at the moment, it's not much better. And Netherlands and I don't know what, and Belgium and bla bla bla… OK, the universities have done certain things: look at Belgium, the circles in Flanders, from Marc [Lodewijckx] the three books, or the Sammi collection or Birger [Stichelbaut] that did the First World War, mapped it for instance. It didn't enter into the system as …

RP – The general practice of archaeology, yes?

DG – That's why the stories or discussions with Rene [Pelegrin]? You don't have a school in order to find a flier. None of us knows what's really going on in France and, more or less, Spain is doing as all the rest of universities, it's university-level work.

RP – Even then, there was some good stuff that came out when we had the conference there [AARG 2015, Santiago de Compostela: see also *AARGnews* 52].

DG – Yes, it was super, super. The bronze age things that we were presented with. There are some really nice things. Mapped and all done.

RP – Yes, but it is not a routine part of their practice is it?

DG – OK, this is an excellent… It's not a part of the practice. Of working in archaeology. They may all know about it, they may all appreciate that this can be done. Nobody can live with it or be a specialist and it is certainly not part of the practice. Practice starts on the ground. Lidar is the only thing which came into it. Not even structural surveys like surveying on the ground and things like that. That would be … brave. They would rather accept that than go for aerial part. And we're not talking necessarily flying, let's just look at the existing archive. And they may not always be adequate to do AP work. So sometimes, you know, it's hard to show how many things are going in a different way than you are used to or that you know which are good and bad sides of it, and I don't know what. And above all, this time before, none of us have. This pre-Second World War background, neither from school or from studying, nor from practice.

RP – What I used to say to Wlodek [Rączkowski] was that we've been doing it for 50 years, you've been doing it for five years – be patient. But I think there's more to it than that …

DG – I think it is. It includes the whole archaeological population, not just the ones who would want to do it or would be ready to go into a special field, or would be ready to try and put double work in order to catch up to some point. You have to first get the other ones to support it as well. So this is a … what would it be … a dead horse…? … So see, when you look at the few people, from all these places, that come [to AARG?]. A lot of them have these background problems. And even if you go to places like Vienna where it's all roses, looking at the whole of Austria it's not that nice.

RP – It's not extended, yes.

DG – And if we look at all Austria, it starts with this neiderostae[?], the Danube in the northern part looks like Pannonia with extended monoculture and I don't know what. The rest of it is damned problematic.

RP – Yes, I did two flights with Michael [Doneus] so I've seen bits of it, and those strip fields … ugh, yes. Patience, patience.

DG – Exactly. Well, you see, I maybe didn't find the right word, but patience is certainly one thing that could bring us here. Take my country, and its patience you need on karst landscape as well. It's all been built from prehistory onwards – all the time. It may be fossilised … but it's still functioning, still working. You know, when you have to decipher what is and what isn't. And if you look at Croatia, that bit that produces classical Pannonian results. Nobody's really doing it, and nobody's interested in doing it. The area between Brana and Sara, which is Pannonian zone.

RP – Are there possibilities of projects there? Research projects.

DG – There *are* projects there. Hrvoje Potrebica [a student on the first training week in Hungary in 1996] is one of them. He's got a big project, it's even international, prehistorical Danube, or trans-Danube prehistory … I don't know what it is, whatever. It's a big international project: Austria, Hungary, Croatia … who else is there?... I don't know. You see, and he's supposed to be someone who's on the top of it, has the research project, and doesn't care if … He's been in the school, wanted to be I don't know what. He's been this year in Appulia, what was he presenting, Sara told us? He is a flipper person [underwater archaeologist]. He's everything.

RP – Oh, OK. But everythings are not all that good, necessarily.

DG – Yup, OK, so let's say that when I say my students, or my students who are now my colleagues, all know about it. This one is sitting on the top. Knows about it, knows about its advantages and I don't know what …

RP – I specialised in the aerial stuff and there are other things that I don't know about, but I would like to think that if I was doing a project that was looking at a landscape, that I would be able to be aware of things that might help it and would try and incorporate them in the work I was doing.

DG – No, they go for every new gadget, as I would call it. This [aerial survey/interpretation] is an old gadget in their mind.

DG – We may be an extreme, we may be a special little point in this thing, but in general how many countries in Europe have their separate quite big problems with aerial work?

RP – Oh, we're back to that, OK.

DG – We have to. OK, we can do this tomorrow morning if you're…

RP – We can probably do it tomorrow morning as well, can't we…

DG – Because it's midnight….

Cropmarks

Harvested by Rog Palmer[1]

(web links were accessed on various dates between mid-April 2019 and mid-October 2019)

From drone to reconstruction
Matt Richie summarises a nice mixture of a drone photogrammetric survey aided by field investigation that leads to a reconstruction drawing of the Iron Age hillfort of Castle Hill above Glentress, Scotland.
https://forestryandland.gov.scot/blog/archaeology-from-sky?fbclid=IwAR0un5xGscgDYt_gGOhtUqyVfLYCAxO1xhB7r8CYMkYvJxeIxDrJPC2RPk8

Sorting out Indian archaeology
An article about Satellite Sarah's latest aims to solve all the problems of Indian archaeology as she has so successfully done elsewhere (e.g. finding Vikings in Canada, Romans in N Africa, etc.).
https://www.nationalgeographic.com/culture/2019/07/solving-india-ancient-mysteries-citizen-archaeologists/

Interpreting satellite images
An article from NASA's website giving 'five tips and strategies' to help interpret satellite images. It must be good because they mention relief inversion if the shadows are wrong.
https://www.earthobservatory.nasa.gov/features/ColorImage?fbclid=IwAR2Hp-iFJEta1jHBaV6Wf55uamHR5ZP4bXr4E0gM60VPWzltLNGPsX9mmGY

Fieldwalking with a drone
Any of you too old, lazy, or disinterested to pick up bits of broken pottery may like this method using a drone and AI. At last, something that auto-extraction can do. The serious article is in *Journal of Archaeological Science* to which I no longer have free access.
https://www.ancient-origins.net/news-history-archaeology/drones-0012629?fbclid=IwAR2Svm6RB39E36U8vuI2WZpluKnBKoLeIClVMWYR2_kmXH8Y50ofZQ3GNas

Improved point cloud generation from drone-collected images
Global Mapper have a new Lidar module that includes enhancements to the module's point cloud editing capabilities. It will cost you a bit as Global Mapper is about editing capabilities. It will cost you a bit as Global Mapper is about €550 as is the price of the Lidar module.
https://www.bluemarblegeo.com/products/global-mapper-download.php

ALS reveals 1000 sites on Arran
AARG members already know about this work, led by Dave Cowley, as a prelude to mapping Scotland. This item includes some pictures.
https://www.bbc.co.uk/news/uk-scotland-glasgow-west-49989351

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Luftfotoarkæologi 2 (Aerial archaeology 2)

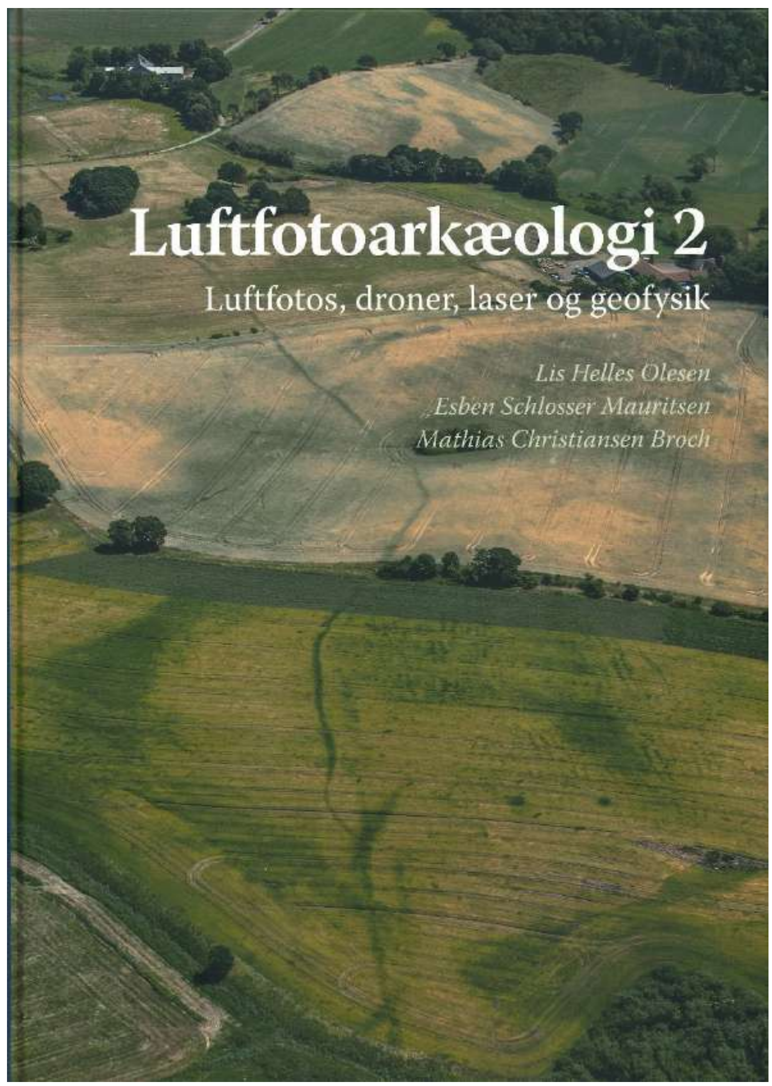
Our new book, *Luftfotoarkæologi 2 – Luftfotos, droner, laser og geofysik (Aerial archaeology 2 – Aerial photos, drones, laser and geophysics)*, presents results from the last five years investigations, 2013 to 2018 and the end of the project. In 2015 our first book, *Luftfotoarkæologi i Danmark (Aerial archaeology in Denmark)*, was published with results from 2009 to 2012.

The project has its base in Holstebro Museum and the authors are the three archaeologists and museum curators, Lis Helles Olesen and Mathias Christiansen Broch, Holstebro Museum and Esben Schlosser Mauritsen, Ringkøbing-Skjern Museum. Many other authors have contributed. Hundreds of flying hours, studies of orthophotos, flying with a drone across prehistoric monuments, use of geophysical methods and modern laser scanning are the basics of the project on which the results in the book are built. Our purpose is to show what a huge amount of information is still lying in the landscape and how much new knowledge we can get with the use of non-destructive archaeology and minimal excavation.

The book is in Danish with a comprehensive summary and all captions in English. It has 396 pages and contains lots of aerial photos, drawings and maps.

The price is 350 Danish kroner (around 47 Euro) + postage (Weight 2,5 kg). Contact: sandie.nielsen@holstebro-museum.dk

Lis Helles Olesen
Lis.helles@holstebro-museum.dk



Books and papers of interest?

Rog Palmer[1]

Borie, C., Parcero-Oubiña, C., Kwon, Y., Salazar, D., Flores, C., Olguín, L. and Andrade, P., 2019. Beyond Site Detection: The Role of Satellite Remote Sensing in Analysing Archaeological Problems. A Case Study in Lithic Resource Procurement in the Atacama Desert, Northern Chile. *Remote Sens.* **2019**, *11*, 869. https://doi.org/10.3390/rs11070869

Use of Landsat 8 images to identify potential chert sources in the Atacama Desert, Chile. Thorough discussion of methods used, problems and results from ground visits may help others who want to do similar things in different places.

Christopher Sevara, MartinWieser, Michael Doneus and Norbert Pfeife, 2019. Relative Radiometric Calibration of Airborne LiDAR Data for Archaeological Applications. *Remote Sens.* **2019**, *11*, 945. https://doi.org/10.3390/rs11080945

Radiometric values have been overlooked by most users of ALS data who have favoured the terrain modelling components. One reason is that it requires specifically to be collected and cannot be used 'off the shelf' in the way more common to height data, especially that from open access sources. However, if your project costs allow it, this paper guides you through the theory, methodology and calibration needed to use the data. A case study comes from an archaeological research project in western Sicily and discuss the relative merits of the uses of radiometric data in such locations as well as its wider applicability for present and future archaeological and environmental research. To encourage more use of radiometric data, a freely-available tool has been developed that allows users to apply the calibration procedure to their own data.

Kalayci, T., Lasaponara, R., Wainwright, J. and Masini, N., 2019. Multispectral Contrast of Archaeological Features: A Quantitative Evaluation. *Remote Sens.* **2019**, *11*, 913. https://doi.org/10.3390/rs11080913

Twenty-three pages that demonstrate scientifically that the same features may appear differently at different times of year. Test data are spectral responses of hollow ways in Upper Mesopotamia.

Deodato Tapete (Ed.), 2018. *Remote Sensing and Geosciences for Archaeology. Geosciences*. https://doi.org/10.3390/books978-3-03842-764-3

This 'Special Issue' open access volume brings together 22 papers that were published individually in *Geosciences*. Some have already been drawn to your attention in earlier issues of *AARGnews*. If you want a real printed version, one can be yours for €85.95.

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Federica Boschi, 2019. Surveying an Adriatic landscape: non-invasive survey approaches to pre-Roman sites in the ancient Ager Gallicus, Italy. *Antiquity* 93, 368, e10 (2019): 1–8.
https://doi.org/10.15184/aqy.2019.31

A contribution to *Antiquity's Project Gallery* that discusses methods (including aerial observation/photography since 2012) used in archaeological survey of the northern Italian Cesano and Misa river valleys. Results have filled in some of the archaeological territory and show the close relation of sites to the physical geography of the region.

Dan Ştefan and Magdalena Ştefan, 2018. Remote-sensing for mountain archaeology in the Curvature Carpathians. The fortifications around Crai's Peak. *Istros* XXIV

This wordy report is in two parts, Romanian and English, separated by the list of figures and references. It also has perhaps the world record for footnotes. The gist of it is examination of earthworks dating to Roman and WW1 periods using UAV, satellite and field investigation at one location within a larger study area.

Ariele Câmara and Teresa Batista, 2017. Photo interpretation and GIS as a support tool for archaeology: the use of satellite images for creating interpretation keys for dolmens. *Journal on Advances in Theoretical and Applied Informatics*, V3-N1, 116-120.

Use of satellite and aerial images on Google Earth and Bing to identify dolmens in Portugal. This may make a good example of finding small objects on single images (ie not stereo). On-screen image examination was done at a 1:20 m (sic) if image quality allowed.

Monterroso-Checa, A., 2019. Geoarchaeological Characterisation of Sites of Iberian and Roman Cordoba Using LiDAR Data Acquisitions. *Geosciences* **2019**, *9*, 205.
https://doi.org/10.3390/geosciences9050205

Based on the abstract: ALS-derived DSMs for the city of Cordoba, S Spain, in combination with geological and archaeological records, provide evidence of the geomorphological reconstruction of the city in ancient times. Using Cordoba as an example, the article highlights the fact that LiDAR data are also useful for the diachronic analysis of ancient urban structures buried some metres deep in current historic cities.

Signoroni, A., Savardi, M., Baronio, A. and Benini, S., 2019. Deep Learning Meets Hyperspectral Image Analysis: A Multidisciplinary Review. *J. Imaging* **2019**, *5*, 52.
https://doi.org/10.3390/jimaging5050052

A summary of the state of the art at the time of writing that may be of intertest to those trying to automate archaeological detection or having to write homework on future possibilities in archaeology. There is a lot about how things are done and a selection of test cases from biomedical applications and uses for food, agriculture and 'other'. A useful appendix describes and explains some of the Deep Learning processes.

Alin Mihu-Pintilie and Ionut Cristi Nicu, 2019. GIS-based Landform Classification of EneolithicArchaeological Sites in the Plateau-plain TransitionZone (NE Romania): Habitation Practices vs. Flood Hazard Perception. *Remote Sens*. 2019, 11, 915; https://doi:10.3390/rs11080915

From the text: … geoarchaeological investigation of the heterogeneous landscapes of the Moldavian Plain (NE Romania) using GIS landform classification and flood hazard assessment has produced valuable information regarding the distribution of 730 Precucuteni and Cucuteni settlements during the Eneolithic period.

Hung, I.-K., Unger, D., Kulhavy, D. and Zhang, Y., 2019. Positional Precision Analysis of Orthomosaics Derived from Drone Captured Aerial Imagery. *Drones* **2019**, *3*, 46. https://doi.org/10.3390/drones3020046

If you are worried that your photo mosaics are not always in the same absolute place, this short paper might make interesting reading.

Sally Evans, 2019. *Historic England Aerial Investigation and Mapping (formerly National Mapping Programme)*. Standards Technical Review. Historic England, *Research Report Series* no. 46-2019. ISSN 2059-4453 (Online). https://research.historicengland.org.uk/Report.aspx?i=16333&fbclid=IwAR0MddfJ7LWngbKVBnteahl5k3uST3S4ptlw5ShAhkPs0PXPA80UjKUGVK0

A detailed review (157 pages, including a few blanks) of the things that HE's aerial mapping people did, do and may do in future, including comments from potential users of problems (eg too many different systems in use for ease of incorporation of AI&M – as we must now call NMP – output into country HERs) and its values to different users. I note that the original aim to map England at 1:10000 seems to have blurred into something that, on the basis that half the country is completed, may be finished by 2050.

Fetai, B., Oštir, K., Kosmatin Fras, M. and Lisec, A., 2019. Extraction of Visible Boundaries for Cadastral Mapping Based on UAV Imagery. *Remote Sens.* **2019**, *11*, 1510. https://doi.org/10.3390/rs11131510

A type of auto-detection that may have some use for archaeologists who want to map field divisions/boundaries. Not a high success rate, but a beginning, and it ought to work on all types of aerial image.

Sarah Parcak, 2019. *Archaeology from Space: How the Future Shapes Our Past*. Henry Holt & Co, 288 pages. ISBN-13: 978-1250198280. £22.10 (Amazon UK).

I haven't read this, but if you want to see an excerpt before wasting your money, there are a few paragraphs scattered around, e.g. at: https://www.livescience.com/65868-archaeology-from-space-excerpt.html

R. Evans, 1990. Crop patterns recorded on aerial photographs of England and Wales: their type, extent and agricultural implications. *Journal of Agricultural Science, Cambridge* (1990), 115, 369-382. For sale at Cambridge Core: https://doi.org/10.1017/S002185960007581X

Yes, 30 years old and discovered by Dave Cowley in July 2019. This paper offers a concise and precise guide to why and where, 'crop patterns of natural origin and man-created crop marks are frequently recorded on aerial photographs taken over England and Wales'. I imagine this is based on Bob Evans' work to compile the 1:250,000 soil maps of those countries as it deals with those even though many of the soils, possibly with different names, occur worldwide. Hopefully most people in the aerial world are aware of the contents from other sources, but this is worth a look if you can get hold of it.

Lei Luo + 14 others, 2019. Airborne and spaceborne remote sensing for archaeological and cultural heritage applications: A review of the century (1907–2017). *Remote Sensing of Environment* 232 (2019) 111280. https://doi.org/10.1016/j.rse.2019.111280

From the abstract: 'In this review … the principles that make passive (photography, multispectral and hyperspectral) and active … (SAR) and … LiDAR imaging techniques suitable for ACH applications are first summarized and pointed out; a review of ASRS and the methodologies used over the past century is then presented together with relevant highlights from well-known research projects. Selected case studies from Mediterranean regions to East Asia illustrate how ASRS can be used effectively to investigate and understand archaeological features at multiple -scales and to monitor and assess the conservation status of cultural heritage sites in the context of sustainable development. An in-depth discussion on the limitations of ASRS and associated remaining challenges is presented along with conclusions and a look at future trends.'

The article is deliberately sourced from and referenced to peer-reviewed journals with content identified using a Scopus (http://www.scopus.com/) search. Thus, very few, if any, of the century's key books are mentioned – in fact the story really begins after 1967 as '… only a dozen contributions were published in the period 1907–1967…' (3). However, the journal contributions may be easier for readers to access by modern means.

Whizzing through, I note that there is a table of satellite MS systems, perhaps useful in conjunction with the longer list that David Danelli published in *AARGnews* 54; examples of hyperspectral images complete with a 'visual interpretation' – what we may call a map – of features noticed; examples of looting; of image processing; a demo of SAR at a place not named in the caption; demos of surface ALS plus some Mayan and USA examples; underwater ALS with an example from Kolone, Croatia … and on it goes, ending with examples generated using UAVs; a comment about auto-detection. The 27-page paper may provide useful overviews for those who haven't already got them.

Tapete, D. and Cigna, F., 2019. COSMO-SkyMed SAR for Detection and Monitoring of Archaeological and Cultural Heritage Sites. *Remote Sens.* **2019**, *11*, 1326. https://doi.org/10.3390/rs11111326

From the abstract: '… the Italian Space Agency (ASI)'s COnstellation of small Satellites for Mediterranean basin Observation (COSMO-SkyMed) has peculiar properties that make this mission of potential use by archaeologists and heritage practitioners: high to very high spatial resolution, site revisit of up to one day, and conspicuous image archives over cultural heritage sites across the globe. .... applications … provide evidence on how subsurface and buried features can be detected by interpreting SAR backscatter, its spatial and temporal changes, and interferometric coherence, and how SAR-derived digital elevation models (DEM) can be used to survey surface archaeological features. … temporal revisit SAR … series can support environmental monitoring of land surface processes, and condition assessment of archaeological heritage and landscape disturbance due to anthropogenic impact (e.g., agriculture, mining, looting). … this paper provides an overview of the capabilities of COSMO-SkyMed imagery in StripMap Himage and Spotlight-2 mode to support archaeological studies, with the aim to encourage remote sensing scientists and archaeologists to search for and exploit these data for their investigations and research activities. Furthermore, some considerations are made with regard to the perspectives opened by the upcoming launch of ASI's COSMO-SkyMed Second Generation constellation.'

Case studies are from Peru, Syria, Italy, and Iraq.

Lalit Kumar and Onisimo Mutang (ed), 2019. *Google Earth Engine Applications*. A reprint of articles from the Special Issue published online in the open access Journal *Remote Sensing* from 2016 to 2019. https://www.mdpi.com/journal/remotesensing/specialissues/GEE Paper copies for about €90.00

This book has no archaeological papers but may interest any who want to extend use of Google Earth beyond just looking at it. GEE includes case studies and algorithms that may have archaeological relevance and use, such as monitoring land use change.
Google Earth Engine: https://earthengine.google.com/

Stott, D., Kristiansen, S.M. and Sindbæk, S.M., 2019. Searching for Viking Age Fortresses with Automatic Landscape Classification and Feature Detection. *Remote Sens.* **2019**, *11*, 1881. https://doi.org/10.3390/rs11161881

The 2007 DHM (Danmark's Højde Model) airborne laser scanning derived digital terrain model (DTM) was used for this study.
From the abstract: First ring detection was applied using the Hough circle transformations and template matching, which detected 202,048 circular features in Denmark. This was reduced to 199 candidate sites by using their geometric properties and the application of machine learning techniques to classify the cultural and topographic context of the features. Two of these near perfectly circular features are convincing candidates for Viking Age fortresses, and two are candidates for either glacial landscape features or simple meteor craters. Ground-truthing revealed the latter sites as ice age features, while the cultural heritage sites Borgø and Trælbanke urge renewed archaeological investigation in the light of our

findings. The fact that machine learning identifies compelling new candidate sites for ring fortresses demonstrates the power of the approach.

Massimiliano David, Gian Piero Milani and Roberto Cassanelli, 2017. Aerial Ostia. Before and After E42. *ArcheomaticA International Special Issue*, 30-35

A paper based on 14 photographs (although the text claims there are 15) taken between 1911 and 1983 that show the spread of excavations and modern development in Ostria, Italy.

Green, A.S., Orengo, H.A., Alam, A., Garcia-Molsosa, A., Green, L.M., Conesa, F., Ranjan, A., Singh, R.N. and Petrie, C.A., 2019. Re-Discovering Ancient Landscapes: Archaeological Survey of Mound Features from Historical Maps in Northwest India and Implications for Investigating the Large-Scale Distribution of Cultural Heritage Sites in South Asia. *Remote Sens.* **2019**, *11*, 2089. https://doi.org/10.3390/rs11182089

Use of historical maps to identify mounds, a sample of which were then checked on the ground. This article has little or nothing to do with use of remote sensing although, if images of sufficient resolution were used, they perhaps it could be used to supplement or replace the ground truthing element. Just a thought.

Comer, D.C., Comer, J.A., Dumitru, I.A., Ayres, W.S., Levin, M.J., Seikel, K.A., White, D.A. and Harrower, M.J., 2019. Airborne LiDAR Reveals a Vast Archaeological Landscape at the Nan Madol World Heritage Site. *Remote Sens.* **2019**, *11*, 2152. https://doi.org/10.3390/rs11182152

No great surprise here. Use of ALS to discover a cultivation system on the Micronesian island of Nan Madol constructed and in use between 1200 and 1600 CE (or AD).

Máté Szabó, 2018. *Repülés a múltba - A légirégészet története* (*Flights into the past - History of aerial archeology*). ZIMedia Kiado, Pecs. ISBN: 978-615-00-3808-7.
Also a free download from Máté's page at: https://pte.academia.edu/

Entirely in Hungarian but a useful source of pictures of pioneers and people, some of whom look younger than they ever can have been – e.g. p.122. As the title suggests, the book is mainly about acquiring aerial images but does include some uses of them.

From the blurb:
The book presents the historical development of aerial archeology from the development of photography and aviation to the use of the latest technologies. It also emphasizes the history of Hungarian aerial archeology and deals in more detail with Hungarian institutions conducting such research.
The book is primarily aimed at university students and the audience interested in the topic. It does not contain notes as a scholarly dissertation, but its informative literature facilitates the opportunity to delve deeper into the subject.

Guyot, A., Lennon, M., Thomas, N., Gueguen, S., Petit, T., Lorho, T., Cassen, S. and Hubert-Moy, L., 2019. Airborne Hyperspectral Imaging for Submerged Archaeological Mapping in Shallow Water Environments. *Remote Sens.* **2019**, *11*, 2237. https://doi.org/10.3390/rs11192237

From the abstract: Airborne hyperspectral data were recorded in the Visible Near Infra-Red (VNIR) spectral range (400–1000 nm) over the submerged megalithic site of Er Lannic (Morbihan, France). The method used to process these data included (i) visualization of submerged anomalous features using a minimum noise fraction transform, (ii) automatic detection of these features using Isolation Forest and the Reed–Xiaoli detector and (iii) morphological and spectral analysis of archaeological structures from water-depth and water-bottom reflectance derived from the inversion of a radiative transfer model of the water column. The results, compared to archaeological reference data collected from in-situ archaeological surveys, showed for the first time the potential of airborne hyperspectral imagery for archaeological mapping in complex shallow water environments.

And on a technical note: The study was based on AHI acquired by Hytech Imaging (Plouzané, France) with a NEO HySpex VNIR-1600 push broom sensor … from 1200 feet with a GSD of 50cm.

The pre-processing, processing and auto anomaly detection is too complicated to summarise so any of you with underwater sites and/or an interest in hyperspectral processing may benefit from reading the full paper.

The Aerial Archaeology Research Group

AARG sees the aerial perspective as integral to the pursuit of key questions in archaeology and heritage, including landscape character, long term landscape change, human ecodynamics, and the experience of place. We are a community of heritage professionals, researchers, students and independent scholars dedicated to education, research and outreach initiatives involving the acquisition and application of data from airborne platforms. AARG provides opportunities for networking, mentorship, and exchanges of ideas on theories, methods and technologies related to aerial archaeology. The organization supports an annual conference, workshops, training schools, and publications.

Membership is open to all who have an interest or practical involvement in aerial archaeology, remote sensing and landscape studies.

AARG is a registered charity: number SC 023162.

AARG homepage. http://aarg.univie.ac.at/

Membership/subscription rates:	Individual	£15.00	17.00 Euro
	Students	£10.00	12.00 Euro
	Institutional	£25.00	29.00 Euro

Subscription reminders may be sent out on January 1

Methods of payment:

Standing Order mandate /Electronic funds transfer

PayPal

Sterling or Euro bank notes

Bank details are available on request for direct payment from overseas.
Please contact the Secretary: aarg.secretary@googlemail.com

Student scholarships. AARG has a limited number of student scholarships for attendance at its annual meeting. These are aimed at supporting bona fide students and young researchers who are interested in aerial topics and may wish to attend.

Anyone wishing to apply should write to AARG's Chairman (aargchair@gmail.com) with information about their interests in archaeology and aerial archaeology, as well as their place of study. The annual closing date for applications to the annual AARG conference is mid-May. Other meetings for which scholarships may be available will be advertised on an ad hoc basis. Support for conference attendance may also come from the Riley Fund (see elsewhere, this issue).

LIDAR IMAGERY FOR THE UNDERSTANDING AND PROTECTION OF HISTORICAL LANDSCAPES IN NORTHERN IRELAND

DfC
Department for Communities
www.communities-ni.gov.uk

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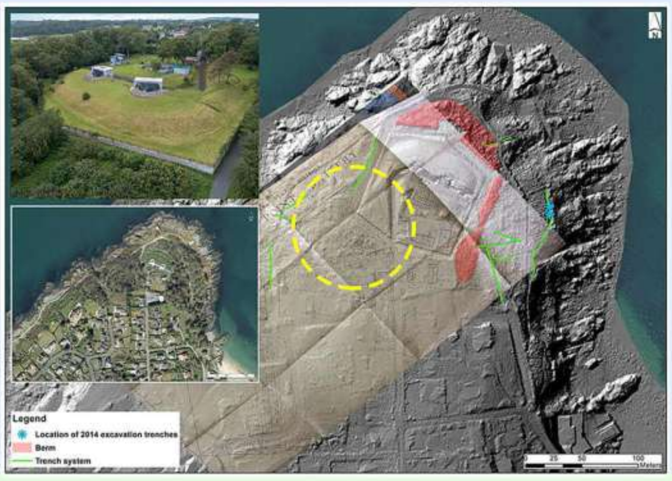
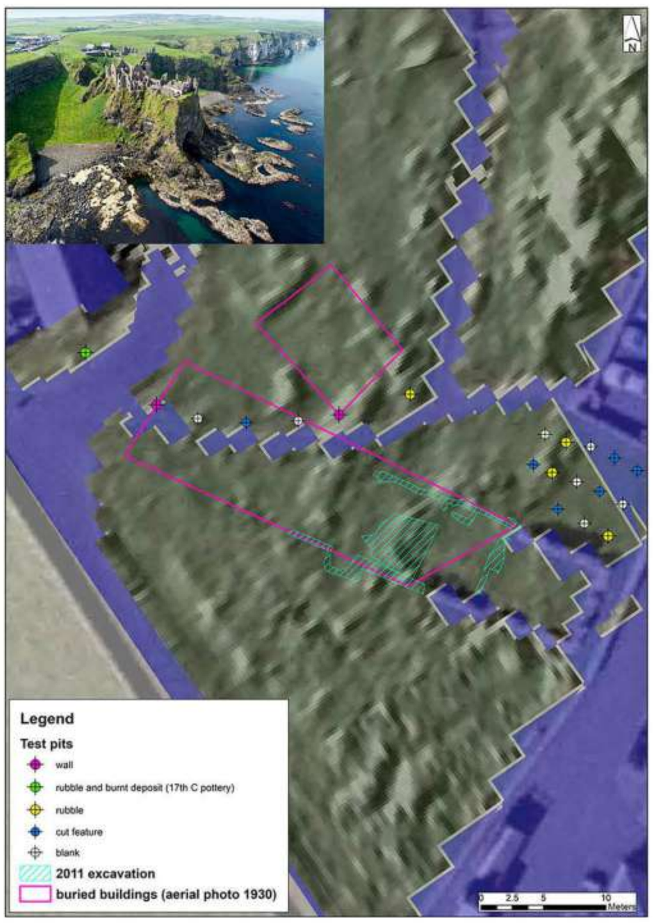
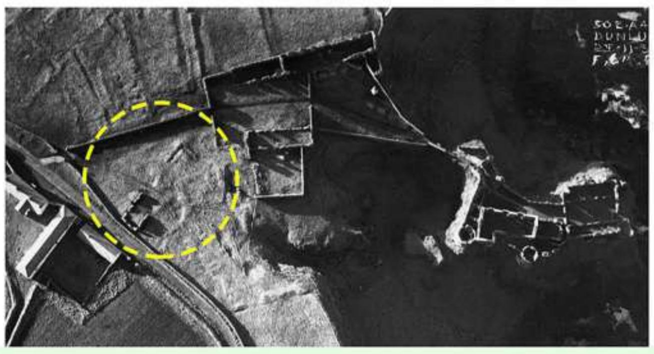
Between 2008 and 2014 the Historic Environment Division (Department for Communities) commissioned BKS Fuego for LiDAR survey of ca 130 sq. km of the territory of Northern Ireland. This imagery, along with the Ordnance Survey (OSNI) River Basin LiDAR coverage (2004/2014), aerial photography and cartography, has been employed to understand State Care Monuments in their surroundings, guide archaeological excavations, assess the condition of sites covered in vegetation and research historical landscapes.

GREY POINT FORT
LiDAR data for the enhanced understanding of the site

Grey Point Fort is a hexagonal coastal battery situated on the southern coast of Belfast Lough, and was established in 1907. Used as a training centre during the First World War, it was fully operational during the Second World War and decommissioned in 1956. Archaeological investigations[1] discovered small segments of what is believed to be a trench system, dug both as training exercise and for defensive purpose in the period 1914-18.
The site is surrounded by thick vegetation cover which hinders the understanding of the trenches and of other earthworks associated with the Fort. The OSNI LiDAR DTM was pivotal to detect various stretches of the trenches, and helped map the full extent of the surviving berm.
An overlay of the DTM and a historical map (made in the 1950s) allowed us to understand the exact location of the barracks that surrounded the coastal battery to the S and SW, and aided the detection of more features. The analysis confirmed the existence of a SW bastion, not yet documented, concealed by the canopy on the aerial views.





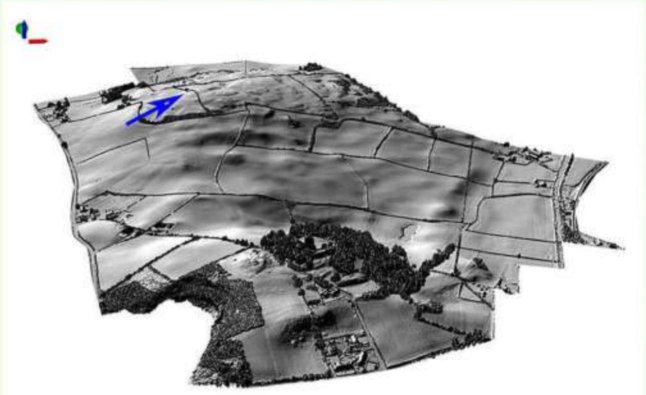


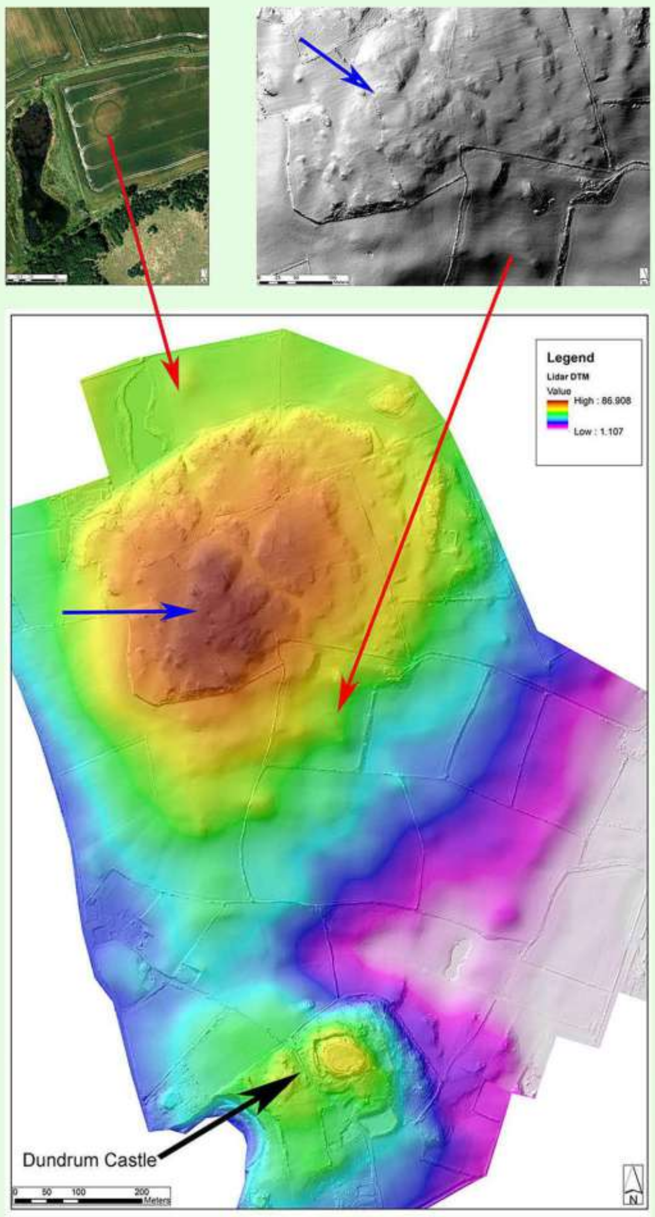
DUNLUCE CASTLE
From remote sensing to archaeological excavation

Dunluce Castle, perched on a cliff of the Antrim coast, was established by the McQuillans (end of 1400s) and later taken over and expanded by the MacDonnells (1550s to 1600s). The Castle and the associated small town were abandoned at the end of the 17th century.
A programme of archaeological evaluation was devised ahead of works to improve visitors' access and safety.
The area to be investigated was the market place of the town, where previous excavations unearthed a 17th century building and a cobbled surface[2].
A 1930 reconnaissance photograph gives evidence of substantial archaeological structures. The LiDAR DTM and electrical resistance data[3] were used to understand the degree of preservation at present.
The combination of these images enabled targeting the structures with the aim of assessing their condition and depth. The excavation revealed, along with other features, two walls belonging to these structures seen on the imagery, most probably dating to the 1600s. The plan of infrastructural works was altered to ensure the full preservation of the structures.

DUNDRUM CASTLE
The wider landscape and the pre-Norman hillfort (dún)

Dundrum Castle was established around 1177 by John de Courcy, an Anglo-Norman knight, on a hill overlooking the tidal inlet of Dundrum Bay in co. Down. The Gaelic name Dún Droma ("hillfort of the ridge"), attested from 1147 AD, and finds attributed to the Early Christian period led to hypothesize the existence of a pre-Norman fort in the same location as de Courcy's fortress[4].
The site was also identified as the place of the hillfort and "great house" described in the Ulster Cycle of Tales[5], which would date to the Iron Age.
A close examination of the LiDAR DTM and DSM, and aerial photography, proved crucial to discover features in the surrounding landscape and suggested that there are other possible locations for the pre-Norman dún. Three subcircular enclosures to the N of the Castle, visible as earthworks (one also as cropmark), confirm that we are looking at a well populated pre-Norman landscape in this area.
One of these enclosures (blue arrow), on top of a hill named Clochrán ("stone causeway"), is interestingly characterised by what seems a funnel-like causeway to the NE. The higher location (see the DSM 3D model left) would have given significant prominence and uninterrupted views across the landscape characteristics shared by other Iron Age hillforts in Ireland.
With higher sea levels, the hill of Dundrum Castle would have been almost as a promontory – a very appealing location for the Norman castle but an inconvenient one for an Iron Age fort and even more so for a Christian site, under the threat of the Vikings' seaborne raids at the close of the 1st millennium AD.





References:
[1] R. Ó Baoill and H. Montgomery, CAF Data Structure Report No.108, Excavations at Grey Point Fort, Co. Down, 2015.
[2] C. Breen, Dunluce Castle: History And Archaeology, 2012.
[3] Centre for Archaeological Fieldwork of Queen's University, Belfast, 2019/10.
[4] McDonald, Data Structure Report: Geophysical Survey and Excavation at Dundrum Castle, County Down 2012 and 2013.
[5] J.J. Phillips, The annals and archaeology of Dundrum Castle, 1883.
J. O'Keeffe, A guide to the historic monuments of Northern Ireland in State Care, NIEA, 2009.

Data:
LiDAR data: www.opendatani.gov.uk
LiDAR 2D and 3D visualisations: C. Botturi
Drone imagery: T. Corey, Historic Environment Division
Orthophotography OSNI

Documenting natural and anthropogenic hazards at the Nasca Lines UNESCO World Heritage site in Peru using satellite SAR

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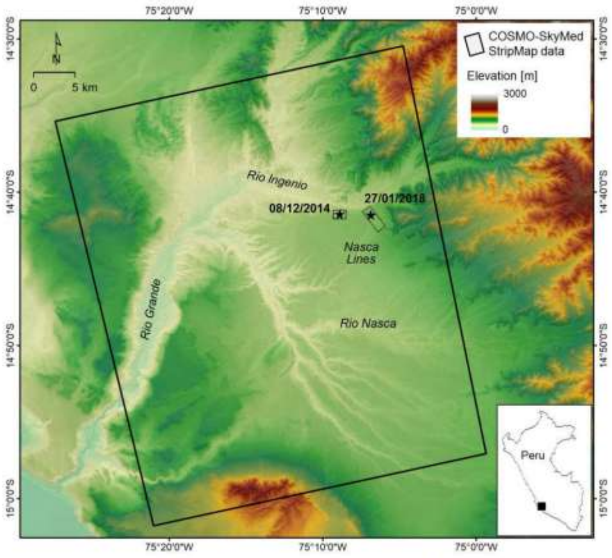
Agenzia Spaziale Italiana

Nasca Lines and Geoglyphs

The "*Lines and Geoglyphs of Nasca and Palpa*" in Peru are among the most well-known UNESCO World Heritage sites globally, and an exemplar of site where heritage assets cannot be separated from their natural and anthropogenic environment. As such, the Lines are exposed to interactions with local weather and natural surface processes, as well as the human presence and its use of the land.



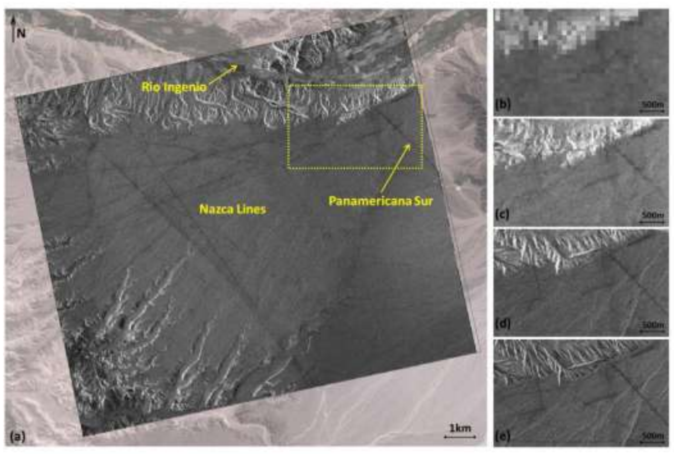
Location of the Nasca Lines region of interest in Peru onto NASA's SRTM DEM, with indication of the COSMO-SkyMed data and areas affected by the 2014 and 2018 events

Source: CIGNA & TAPETE 2018, Remote Sensing, 10 (4), 572; doi:10.3390/rs10040572

VHR imaging with TerraSAR-X and COSMO-SkyMed SpotLight

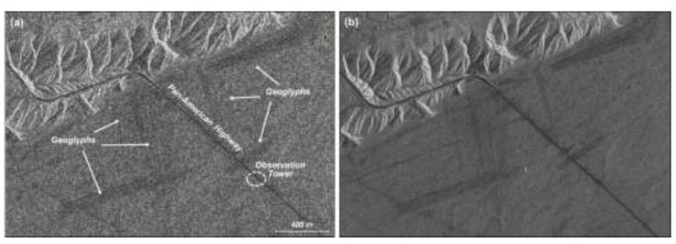
Archaeologists can benefit from the full range of beam modes and incidence angles offered by the same satellite mission to improve the detection and delineation of subtle archaeological features.

Analysis of TerraSAR-X and COSMO-SkyMed data demonstrates the stunning improvement in SAR imaging capabilities to discriminate the Lines. The distinctive radar signature of the 'negative geoglyphs' (exposed unpatinated and lighter coloured ground) with respect to the nearby soil (dark gravels) becomes more and more apparent when moving from ScanSAR, to StripMap and Spotlight modes.



(a) TerraSAR-X SpotLight scene at 1 m spatial resolution acquired on 13/08/2008 over the Lines. Comparison of multi-looked: (b) ScanSAR (res. 18 m); (c) StripMap (res. 3 m); (d) SpotLight (res. 1.7–3.5 m); (e) High Resolution SpotLight (res. 1.1–3.5 m) (© DLR 2016)

Source: TAPETE & CIGNA 2017, JOAS-Reports, 14, 716-726; doi:10.1016/j.jasrep.2016.07.017



Comparison of COSMO-SkyMed ascending mode scenes acquired on (a) 05/07/2018 in StripMap HIMAGE mode (3 m resolution) with HH polarization and 27° incidence angle, and (b) 16/07/2018 in SpotLight-2A Enhanced mode (1 m resolution) with VV polarization and 39° incidence angle.

Source: TAPETE & CIGNA 2019, Remote Sensing, 11 (11), 1326; doi:10.3390/rs11111326

The experiments with VHR SAR confirm that data archives such as those being built for Nasca by COSMO-SkyMed, prove valuable for analysis of surface features and archaeological assets up to the local scale, with an imaging resolution similar to that of VHR optical data.

The analysis of the 2014 and 2018 incidents occurred at the Lines also showcases that these data can be used for retrospective analysis, digital recording and substantiation of landscape disturbance events from space, and thus act as essential sources of geospatial information on the condition and conservation history of archaeological assets.

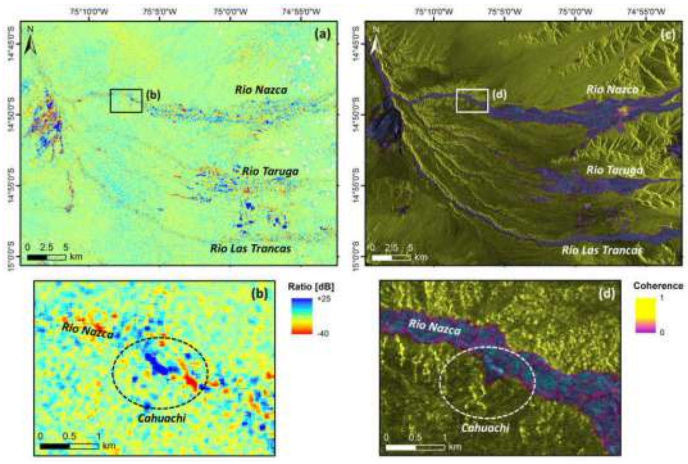
SAR and InSAR change detection

To document the Lines and detect events of natural and human-induced landscape disturbance occurred over the last three decades, we use SAR data acquired by the Copernicus Sentinel-1 constellation and its contributing missions. In particular, we carry out:

- Regional and river catchment scale assessments of landscape changes and condition of heritage assets, using long series of ERS, ENVISAT and Sentinel-1 IW C-band (λ=5.6 cm) SAR data at ~25 m ground resolution acquired since the 1990s
- Local and site scale studies, based on tailored acquisition campaigns of COSMO-SkyMed and TerraSAR-X X-band (λ=3.1 cm) SAR imagery, with up to 1 m ground resolution

Our data analysis methods include:

- Amplitude-based change detection, via RGB color composition and ratioing (R) of radar backscatter (σ^0)
- Phase-based (φ) approaches, exploiting Interferometric SAR (InSAR) coherence (γ)



Change detection based on (a,b) ratioing and (c,d) coherence from ENVISAT scenes acquired on 02/10/2005 and 07/10/2007 (B_p=4 m). The dotted circles highlight (b) changes in the σ^0 and (d) loss of coherence likely due to archaeological excavations in the area of the ceremonial centre of Cahuachi.

Source: TAPETE & CIGNA 2017, JOAS-Reports, 14, 716-726; doi:10.1016/j.jasrep.2016.07.017

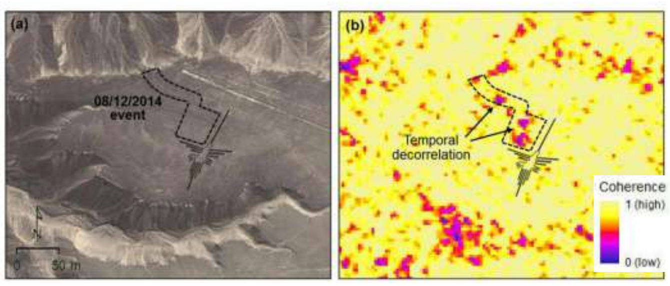
COSMO-SkyMed view of the 2014 surface disturbance event

The Peruvian Ministry of Culture reported that on 08/12/2014 environmental activists accessed the area near the Hummingbird geoglyph, and unfurled tall, yellow cloth letters under the bird's beak to compose a message.

On site inspections highlighted that the route followed to access the geoglyph was irreparably marked, in addition to the disturbance of the surrounding terrain due to the circulation of people. The latter affected a rectangular area with an extent of ~1600 m^2.

Analysis of cross-event COSMO-SkyMed pairs allows the identification of noticeable decorrelation features to the west and northwest of the Hummingbird. The features match very well with the area where the disturbance occurred, including both the area where the activists message was temporarily installed and the access route.

In post-event pairs, the plateau generally shows high coherence, thus indicating absence of recent surface disturbance in the area of the geoglyph. Only a few spots of coherence loss can be observed in the valleys around the plateau, due to geometric decorrelation.



(a) Google Earth overview of the Hummingbird geoglyph plateau (VHR image © 2018 DigitalGlobe), with indication of the area affected by the 08/12/2014 incident; and (b) InSAR coherence for COSMO-SkyMed StripMap HIMAGE cross-event pair 10/07/2014–12/04/2015 (B_p=14 m) at 3 m resolution

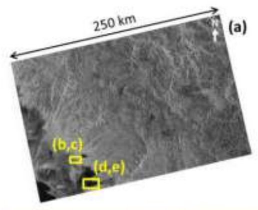
Source: CIGNA & TAPETE 2018, Remote Sensing, 10 (4), 572; doi:10.3390/rs10040572

Detecting landscape changes with ERS, ENVISAT & Sentinel-1

A number of σ^0 ratio and coherence maps were generated based on ERS, ENVISAT and Sentinel-1 image pairs to detect landscape changes occurring at catchment scale within the Rio Grande drainage basin.

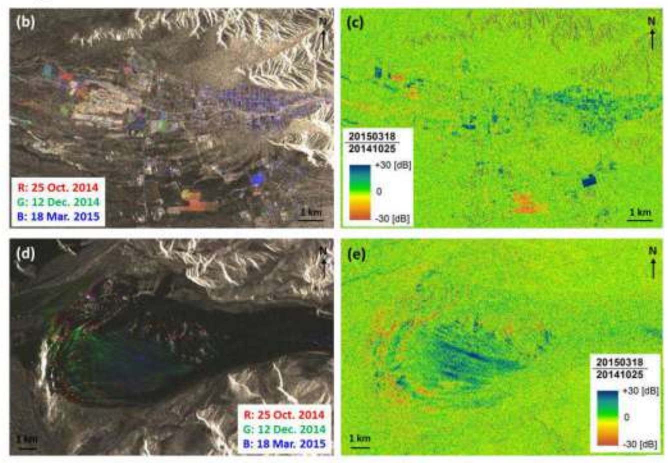
Multi-temporal analysis of the copious SAR archive available for the Lines allows the identification of changes in the landscape induced by variations in land surface properties due to natural processes (e.g. mass movements, soil moisture changes), agricultural practices and other anthropogenic activities (e.g. excavations, vehicle transit).

Significant patterns of σ^0 change and loss of coherence were observed in the floodplain of Rio Nazca, also in proximity to Cahuachi, the world largest adobe ceremonial centre. The latter are due mainly to authorized archaeological excavations and, in a few cases, illegal digging and archaeological looting.



(a) Sentinel-1 IW image of the Rio Grande drainage basin in Peru acquired on 25/10/2014 with VV polarization. (b,d) RGB colour composites and (c,e) image ratios for (b–c) Rio Taruga where soil moisture changes can be recognised in the agricultural fields along the river plain and (d–e) a sand dune where wind-driven mass movements occur.

Source: TAPETE & CIGNA 2017, JOAS-Reports, 14, 716-726; doi:10.1016/j.jasrep.2016.07.017



Tracking the 2018 "plowing" event with COSMO-SkyMed

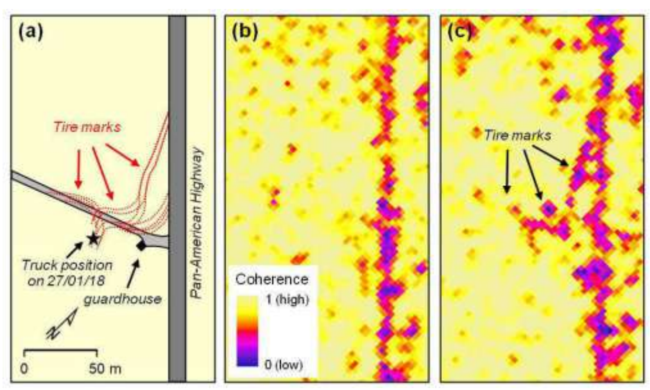
A press release by the Peruvian Ministry of Culture reported that, despite the warning signage indicating the heritage site and prohibiting access to the protected area, on 27/01/2018 a truck diverted off the Pan-American Highway at km 424 and entered the protected area.

Aerial photos revealed that the incident visibly disturbed the area. The truck crossed over 3 linear geoglyphs, and left deep tire marks across a 50 m by 100 m area. The fragile surface of the Pampa de Jumana was altered due to the removal of reddish pebble and uncovering of the lighter grey-yellow clay underneath.

Photographs of the "plowing" incident occurred on 27/01/2018

Pre-event coherence maps show no obvious decorrelation marks other than those along the highway due to vehicle transit, and a few spots of possible human/vehicle transit along the verge of the highway.

On the other hand, some very noticeable marks appear in the cross-event COSMO-SkyMed pairs. The decorrelation marks seem to overlap the exact path that was followed by the truck during the incident, with the main linear feature originating from the highway and moving off it towards the guardhouse.



(a) Sketch of the 27/01/2018 incident, with indication of the tire marks left by the truck; and InSAR coherence for the COSMO-SkyMed StripMap HIMAGE pairs: (b) 18/01/2018–26/01/2018 (pre-event; B_p=4 m) and (c) 13/12/2017–30/01/2018 (cross-event; B_p=19 m) at 3 m resolution

Source: CIGNA & TAPETE 2018, Remote Sensing, 10 (4), 572; doi:10.3390/rs10040572

CIGNA F., TAPETE D. 2018. **Tracking Human-Induced Landscape Disturbance at the Nasca Lines UNESCO World Heritage Site in Peru with COSMO-SkyMed InSAR**. *Remote Sensing*, 10 (4), 572; doi:10.3390/rs10040572

Acknowledgements

COSMO-SkyMed® Products © ASI, delivered under a license to use by ASI. TerraSAR-X data provided by DLR via the LAN1881 grant. ENVISAT data provided by ESA via the Cat1-11073 project. Sentinel-1 data accessed from ESA's Sentinels Scientific Data Hub.

Mapping Medieval Merv

How to interpret complex urban archaeological topography?

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ROOTS – Social, Environmental, and Cultural Connectivity in Past Societies

Abstract

The city of medieval Merv is a large, mostly undisturbed, urban archaeological site in Turkmenistan. The archaeological topography of the site has been captured in UAV derived photogrammetric images/DSMs. This affords the opportunity to map and analyze the site to further explore how its urban structure relates to it social history and development. Before this can be attempted, however, the archaeological topography shown in the imagery must be interrogated and interpreted. Archaeological topography may be interpreted in different, yet valid ways, but what approaches can be taken to handle the ambiguities present in complex urban archaeological topography? Can a framework for interpreting urban archaeological topography be constructed?

Introduction

Beginning as a suburb of an earlier city (*Guyur Qala*), Medieval Merv developed into a city itself in the 8th Century C.E. and prospered as a center of Islamic scholarship and major hub along the "Silk Roads" until its sacking in 1221 C.E. by the Mongols. Medieval Merv - also now known as *Sultan Qala* - covers and intramural area of roughly 600 hct. and, although few structures are partially standing today, much of its topographic features are visible. Existing during the early period of Islamic imperial expansion through to the height of the "Islamic Golden Age", the topography/morphology of Medieval Merv should represent some of the historical and social developments that occurred over those centuries. Moreover, the analysis of the city's topography can expand our understanding of the regional expressions of "Islamic" cities, beyond the classic "Arab" model, and how they worked.

Figure 1: Intramural *Sultan Qala*, from ESRI

To understand how the topography relates to its social and historic of developments, the imagery must be examined and understood, the urban features identified and mapped, and the relationship between the features ascertained. However, as those who are familiar with aerial archaeology will be aware, rarely is the visible aerchaeology plainly defined and identifiable. This matter appears even more pronounced when attempting to interpret the remains and intricate topography of a moldering ancient city.

With the aforementioned considerations in mind, this research project asks two main questions:

1. What does the topography/morphology of medieval Merv tell us about its history? Specifically, what does it tell us about its socio-economic relations and diachronic development, and about early Islamic urbanism in Central Asia, more generally? And how do we relate medieval Merv to the concept of the *Islamic/Muslim city*?
2. How can the interpretation of complex urban archaeology be managed, especially as expressed in remote/aerial data? Can an interpretive method and theory be outlined?

This poster is primarily concerned with the second question, and consequently is aimed at garnering constructive input.

Data

This project chiefly utilizes 2 - 4cm resolution UAV derived photogrammetric imagery, from which 3 band and DSM mosaics are obtained. This data has been procured and generously provided to me by Dr. Gai Jorayev of the Ancient Merv Project, at the Institute of Archaeology, University College London.

Figure 2: Photogrammetric 3 band tiles at 4cm resolution

The advantages of using photogrammetry are the ease of acquiring a high resolution, both photographs and DSMs can be obtained, and that it is rather inexpensive compared with other means of remote sensing such as LIDAR.

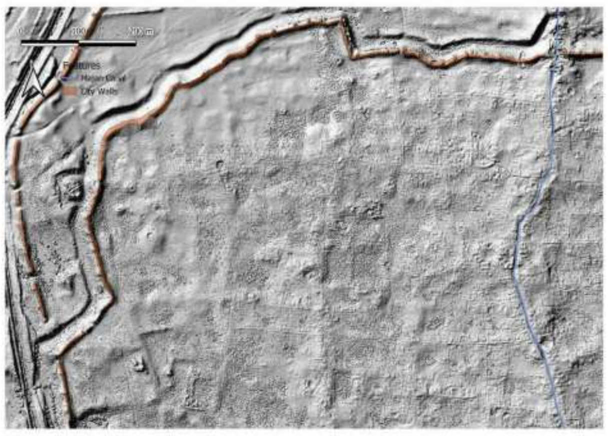

Figure 3: Photogrammetric DSM tiles at 4cm resolution with hillshade (altitude 45°, azimuth 315°, z factor 3.0)

In comparison to LIDAR which has more accessible means of being manipulated, photogrammetry seemingly has significant limitations and disadvantages - at least in my experience thus far - when processing the data. For instance, it is even difficult to derive DSMs and DEMs without loss to the precision of the data, which can be considerable with shallow relief topography, as in the case with *Sultan Qala*. Consequently, other methods of enhancing the relief, such as Local Relief Modeling (LRM) and Sky-View Factor (SVF), are likewise not derivable.

Other Imagery

Fortuitously, the site was aerially photographed in Russian expedition during the 1970's. As can be seen in Figure 4, with a high contrast applied the relief is markedly enhanced. These images are further useful in detecting any change to the landscape and condition of the archaeology.

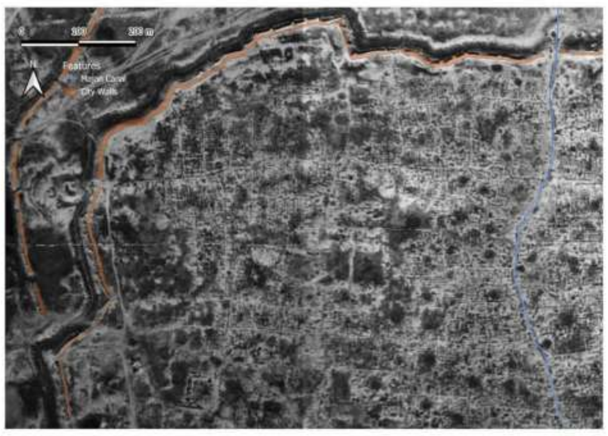

Figure 4: Soviet aerial photos ca. 1970's

Methods Explored and Pursued

The work for this research, presented here, is carried out using QGIS.

Image Manipulation and Enhancement

As explained above, I have found that many of the tools for enhancing relief are difficult or not implementable with photogrammetric DSMs. Similarly, tools such as "curvature," "aspect," and "slope" have produced results that are, at best, comparable to hillshade. Much of the difficulty and ineffectiveness I attribute both to the shallow relief of the site, and the inability to extract/smooth the vegetation, which creates a pixelated-like effect.

The most effective approach, thus far, has been to experiment with manipulating the hillshade; that is to say, adjusting the values for the azimuth, altitude, and z value, as well as using multidirectional hillshading. Blending the 3 band and greyband images with the hillshade also helps in enhancing the relief.

Transcription

In order to manage the ambiguity in feature identification, it may be fruitful to devise a tiered classification system based on degrees of interpretive confidence. This would also entail reaching multiple conclusions with differing degrees of confidence. While a significant portion of the features have been transcribed and mapped (Figure 5), they are still only descriptive in their interpretation and classification, as I am still in the stage of exploring methods that might mitigate the ambiguity of the topography.

In addition to the system described above, the features will also be classified according to their attributes: size (dimensions and area), orientation, and spatial distribution. This will help to identify the features, as well as understand how they relate(d) to each spatially and even diachronically.

Some of the work so far...

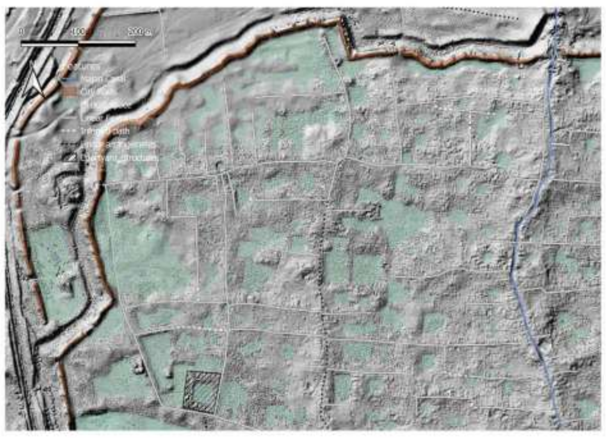

Figure 5: Transcribed features with a DSM background

Advice and Thoughts?

I welcome any constructive ideas, recommendations, and criticisms!

Forthcoming Data

Fieldwork aimed at conducting targeted geomagnetic surveys is currently planned for September 18th - 26th! Though the resulting data may not necessarily reveal what architecturally is being detected, it should provide some welcome well defined images of the architecture, which will be beneficial for mapping.

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Acknowledgements

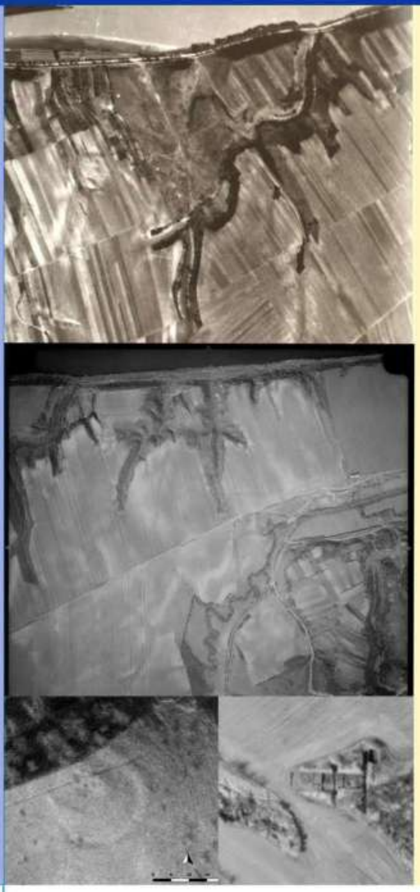
I am very grateful to Tim Williams and Gai Jorayev of the Ancient Merv Project, at UCL for providing the data, without which the project would not be possible. I am additionally thankful to my advisors Prof. Dr. Ulrich Müller and Prof. Dr. Bethany Walker for providing me with invaluable methodological and theoretical support.

From the archive to the RPAS based 3D photogrammetry

The investigation of an Early Iron Age site-complex in Süttő (Hungary)

CZAJLIK, Zoltán * - RUPNIK, László ** - BÖDŐCS, András*

Benefits of the archives

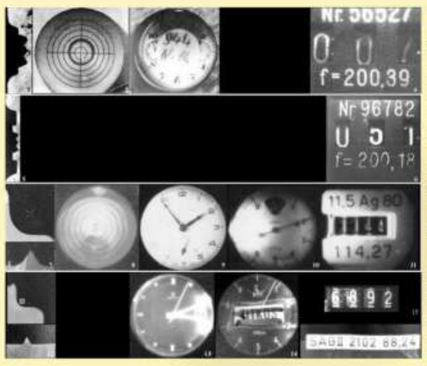


Vertical aerial photographs were first used at the birth of the Hungarian aerial archaeology in 1920's. Unfortunately these photos are almost completly lost. The earliest coherent series of vertical photos in the archive of the Museum of Military History in Hungary were taken in 1940 along the Danube.

From this date the landscape's changes around Süttő could have been followed on various vertical photographs until 1987. These are partly "off-line" accessible in the Museum's Archive (1951, 1954-55, 1970, 1984, 1986) or partly free accessible via internet (Fentrol.hu - 1960, 1975, 1987) thanks to the intensive digitisation works of various Institutes.

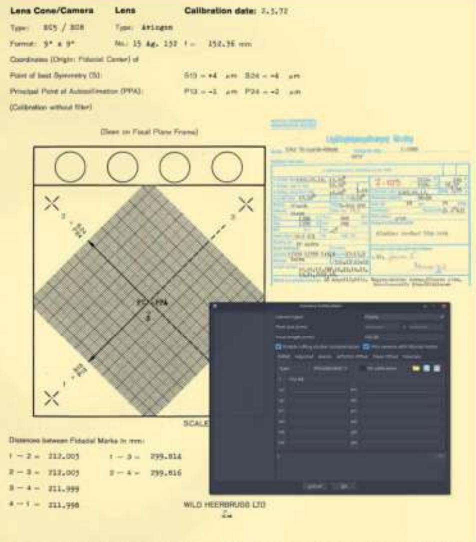
With the help of archive material we could identify new site details (like roman age watch tower - *lower left*) or we could localize the exact position and trenches of former excavations led by Gábor Vékony in the end of 80's (*lower left*).

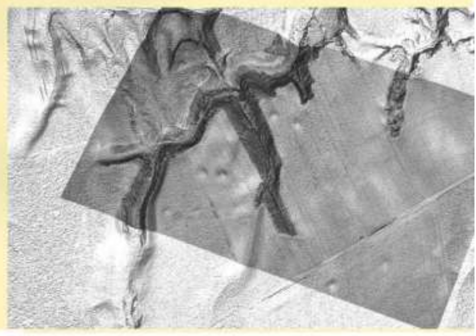
All these flights were accomplished by the Hungarian People's Army.



With the examination of the photo's additional informations, like fiducial marks, objective serial number, etc. *(left)* very interesting techno-historical observations could be realized (e.g from the beginning of the military mapping after WWII in Hungary) in those cases as well, where we do not know the flights details.

Fortunately the digitized archives con-tain not only photos but also descriptions, records from the flight or camera ca-libration reports. These informations mean treasure for the 3D mapping softwares. The exact parameters of the cameras can be set up for a better 3D result. The resolution of these photos cannot be compared with those which are taken by new cameras mounted on drones, but they are giving a much better analysation tool in our hand in archive photo information processing without the com-plicate stereo-comparator.

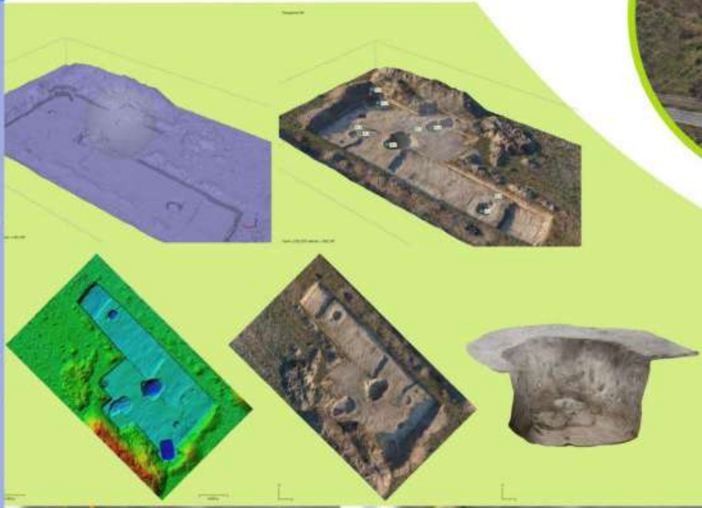


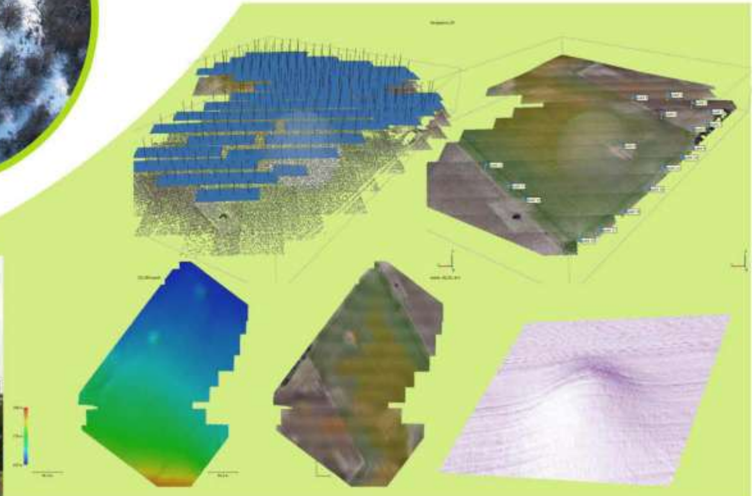


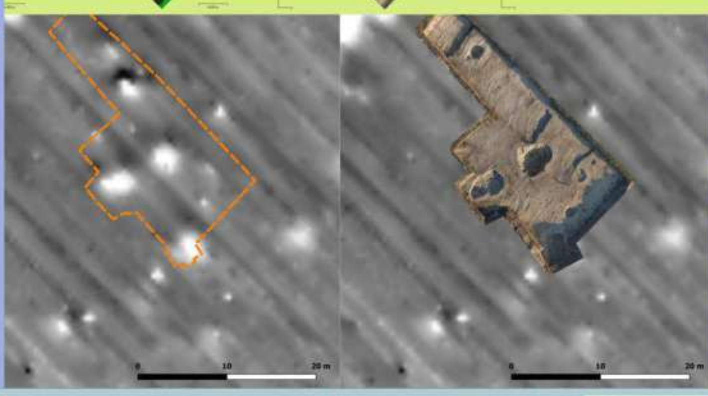
In the framework of the Interreg DTP Iron-Age-Danube programme, we have had the opportunity to use different helicopters for aerial archaeology. The flights have been undertaken between 2017-2019 with Robinson 22 and 44 machines. The main goal was to take pictures from possible small altitude (maximum 30 m above the trees), as because we assumed that the burials could be better observed in snowy circumstances. Though the flights were performed in almost ideal meteorological conditions, they resulted only in data which reinforced the digital models. The helicopter-flights seem to be very usefull from 3 different aspects: illustrating the ramparts/burial mounds in their actual natural conditions, popularising landscape archaeology and creating movies about aerial archaeology.

Site reconnaissance and monitoring

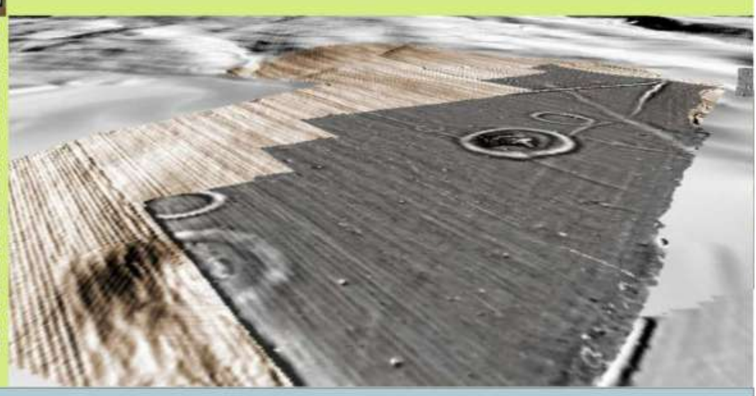
On the way of 3D data processing







As part of our project the RPAS technology has been also implicated for 3D mapping of the site and the excavations as well. The platforms were two different modifications of the DJI Phantom 4 series. During topographic survey we have predefined the optimal flying path, altitude and capturing scenario in DJI Ground Station Pro environment. The flights were carried out in 72 meters relative height, with 80% frontal and 60% side overlapping between the images in the case of the southern burial mounds (*right side*). We used GCPs in the surveyed area in order to improve the accuracy of the digital surface model (DSM) derived from 85 million points. The ground points were also classified. So came up a high-resolution DEM and an orthophoto mosaic which can be compared with other remote sensing data, ALS and magnetometer measurements for example. A small-scale excavation was also carried out which was documented using ground based and airborne photogrammetry as well (*left side*). The drone was manually piloted in this case. The images were typically taken from the altitude between 4 and 20 meters. Beside the verticals, oblique images were also captured in order to reduce the number of blind-spots and obtain better texture for the 3D modelling.



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This project is supported by the Danube Transnational Programme funded under the European Regional Development Fund and co-funded by Hungary

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GIS-BASED MAPPING PROGRAMME OF BOHEMIAN ARCHAEOLOGICAL LANDSCAPE HERITAGE FROM AERIAL PHOTOGRAPHS

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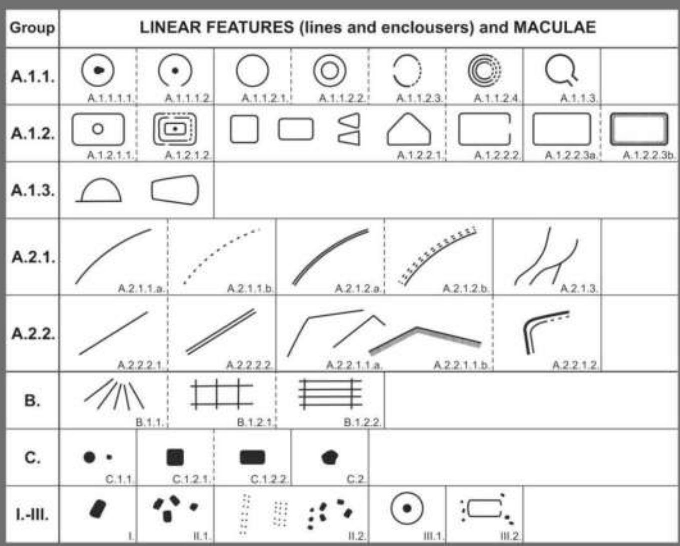
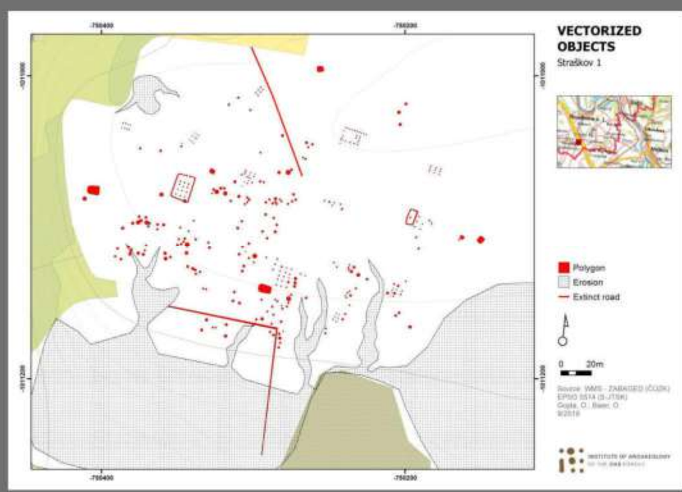
The identification of crop-marked relics of past settlement activities by means of active-interpretive aerial prospection and via the analysis of aerial photographs and satellite imagery contributes largely to the quantitative enrichment of (national, regional, local) sites and monuments records. For the purpose of the central Czech archaeological information system *Archaeological map of the Czech Republic* a production of digital sites and monuments maps/plans based on interpreted aerial images gathered during the 1992 – 2015 programme on aerial reconnaissance (Inst. of Archaeology, Czech Academy of Sciences, ***figs. 1 - 2***) was launched recently.



1. Types of features and their morphology as evidenced during aerial reconnaissance campaigns in Bohemia. A.1.: enclosures; A.2.: lines; B: system of lines; C.: spot features ("maculae"); I: solitary macula; II: structured/non-structured cluster of maculae of the same type; III: combination (intentional, coincidental) of maculae and enclosures. Project of Institute of Archaeology, Czech Academy of Sciences (after Gojda 2017).

2. Perfectly cropmarked early Iron Age above-ground houses (2, 3), a prehistoric sunken house (1), and irregularly dispersed settlement pits (4) at Straškov, distr. Litoměřice (see also figs. 4 and 5).

4. Rectified oblique photograph placed via the GIS ArcMap to the internet orthophotomap server (*www.mapy.cz*). Archaeological content (red lines and dots) is vectorized in a shapefile (Straškov, distr. Litoměřice; see also figs. 2 and 5).

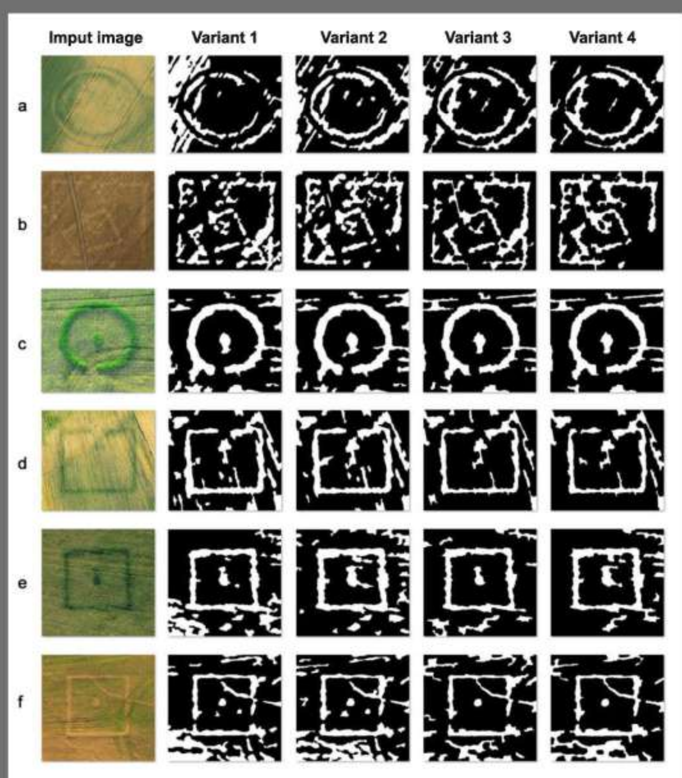


5. Final detailed plan of the site Straškov (distr. Litoměřice) as processed in GIS ArcMap; see also figs. 2 and 4.

This poster brings a report on the applied GIS-based mapping method and presents a few examples of final products - orthorectified and georeferenced digital maps. The production of such plans is carried out in GIS environment and aided by aerial georeferenced orthorectified photographs free available on the internet map server *www.mapy.cz* (***fig. 3***) and on the geoportal of the *State Administration of Land Surveying and Cadastre* (*https://geoportal.cuzk.cz*). Based on this imagery, oblique photos are rectified (***fig. 4***) and their interpreted archaeological content is vectorized. Since the opening of the mapping programme more than 100 sites have been orthorectified and vectorized and, thus transformed into precise plans (***figs. 4 - 5***).

Presented is also a draft of generally applicable methodical procedure based on (semi)automated vectorisation of crop-marked buried features interpreted as features/sites of ancient and historical origin (***figs. 6***).

3. Orthophotos of the Ctiněves site (north-west Bohemia) from the years 2006 (bottom left), 2012 (top left), 2015 (top right) and 2016 (bottom right) as recorded on the internet orthophotomap portal *www.mapy.cz*. Cropmarks of a huge amount of pits, two rectangular ditched enclosures and other structures are well recognisable on images taken in June 2006 and 2016.



6. Assorted entry images and outputs from four variants of pre-processing algorithm of rectified obliques photographs.

Observations with COSMO-SkyMed SAR in support of detection of archaeological sites and monitoring of cultural heritage in ordinary times and crisis

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COSMO-SkyMed mission

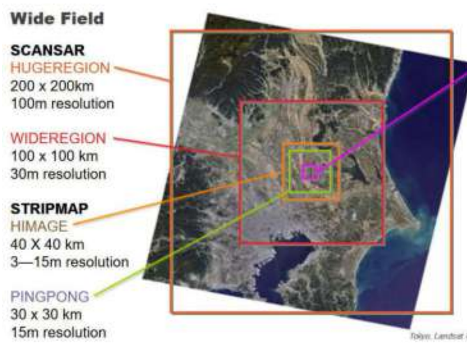
The Italian Space Agency (ASI)'s Earth observation constellation COSMO-SkyMed is the only Synthetic Aperture Radar (SAR) space mission made of four identical satellites operating in X-band (3.1 cm wavelength), that were launched on 8th June (CSK1) and 9th December 2007 (CSK2), 25th October 2009 (CSK3), and 6th November 2010 (CSK4).

Since 2011 when it was fully deployed and operational, the constellation provides consistent single-shot and time series of SAR images acquired in different imaging modes. The most suited for archaeological applications are:

- **Enhanced Spotlight** (1 m ground resolution) for local/site-scale investigations and fine archaeological mapping (10 km x 10 km)
- **StripMap Himage** as the best trade-off between spatial resolution (less than 5 m) and areal coverage (40 km x 40 km)

CSK1 and CSK2 are mutually positioned at 180°, CSK4 is at 67.5° with respect to CSK2 and they form the "tandem-like" configuration at 1-day revisit time, while CSK3 is positioned at 90° with respect to CSK2. Therefore, the temporal frequencies of acquisition range from 16 up to 1 day (interferometric sequence equal to 4-3-1-8 days).

Single co- or cross-polarizations (HH or HV or VH or VV) are available, with alternating polarization in PingPong mode only (HH/VV or HH/HV or VV/VH).

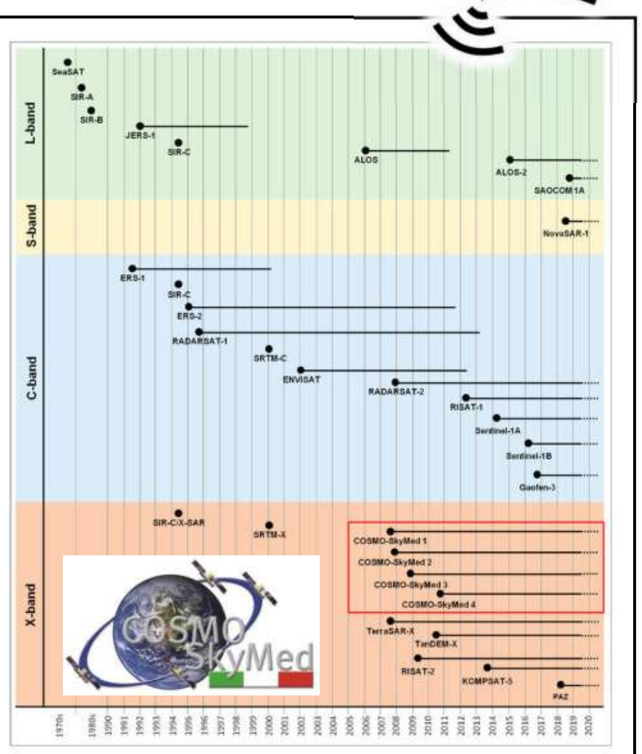


COSMO-SkyMed imaging modes and resolutions.
Source: APONI 2007, IICWG

Acquisitions can be specifically tasked. However, for cultural heritage applications and archaeological prospection it is worth citing that COSMO-SkyMed has a background mission implemented since 2011 as a low-priority acquisition plan allowing the system exploitation to be maximized and consistent datasets to be collected, thus creating a strategic historical archive across the globe.

Designation as a UNESCO World Heritage List site is among the main area selection criteria included in the background mission, in recognition of the "economic and strategic relevance" of these sites. Therefore, the COSMO-SkyMed data archive represents **a unique source of historical records of UNESCO sites** that otherwise would have been lost.

For monitoring and change detection purposes, this is an asset.



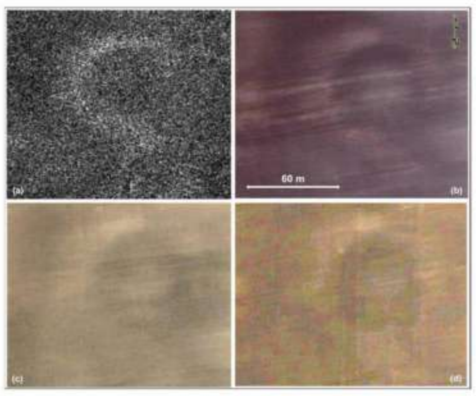
COSMO-SkyMed constellation in the context of past and current satellite SAR systems distinguished by radar band as of 2019.

Archaeological prospection

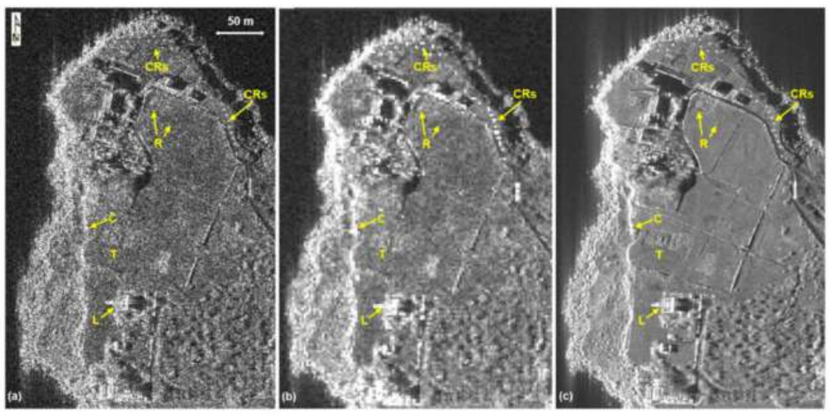
Despite the claim that X-band SAR can penetrate the soil less than longer microwave wavelengths (e.g., L-band, 15 cm), in certain conditions it can be used to identify cropmarks, also owing to the high spatial resolution.

Signal penetration depths are an inverse function of water content (more water within the target, higher the backscatter, stronger the radar return). Moisture content retained by a buried feature may increase the dielectric constant and generate an anomaly ("damp mark").

Owing to the short site revisit, long series of SAR images can be collected consistently regardless of environmental and weather conditions. By multi-temporal averaging the full data stack, an enhanced, very high resolution image of the study area can be generated and recognition of surface features is therefore eased.



(a) Backscattering anomaly in bare ground observed in a COSMO-SkyMed Enhanced Spotlight image acquired in summer with incidence angle of 39° vs. soil/damp mark visible in Google Earth images (© 2019 Maxar Technologies) acquired in (b) summer, (c) autumn and (d) winter.

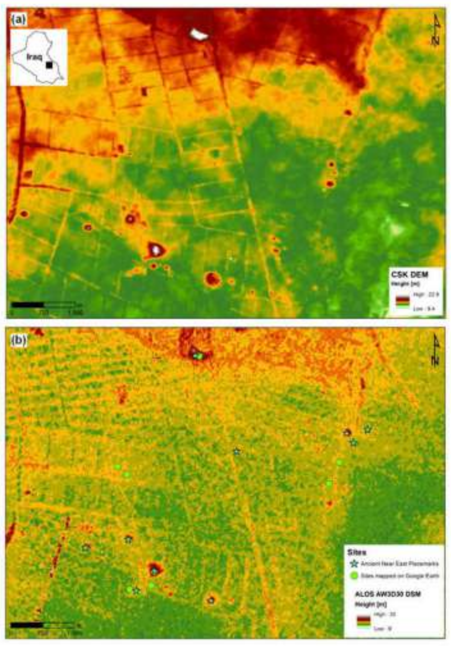


COSMO-SkyMed Enhanced Spotlight image (14/08/2018) in descending mode, incidence angle of 42°, over the archaeological site of Capo Colonna, southern Italy: (a) prior; and (b) after multi-looking. (c) Multi-temporal average of 54 COSMO-SkyMed Enhanced Spotlight images acquired in 2017–2018, improves the recognition of archaeological ruins and structures.

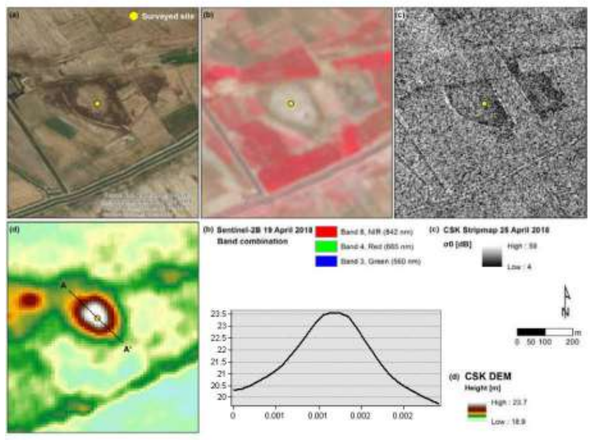
Topographical surveying

Interferometry is one of the key image processing methods that COSMO-SkyMed data can allow. With 1-day interferometric configuration, generation of Digital Elevation Models (DEM) is therefore possible. Nevertheless, the constellation has been poorly requested so far by archaeologists to access DEM products.

In the figure on the left we showcase the level of accuracy achieved by the COSMO-SkyMed StripMap DEM at 10-m posting in the region of Wasit (Iraq), and the fine delineation of even the smallest mounds that were not clearly identified in the lower resolution ALOS Global Digital Surface Model (AW3D30 DSM). The topographic features found in the COSMO-SkyMed DEM match extremely well with known sites and those mapped through Google Earth.



(a) High resolution 10-m posting DEM obtained from a tandem pair of COSMO-SkyMed StripMap Himage scenes acquired in May 2018, and (b) 30-m resolution ALOS Global Digital Surface Model (AW3D30 DSM) over a study area within the Wasit region in Iraq.



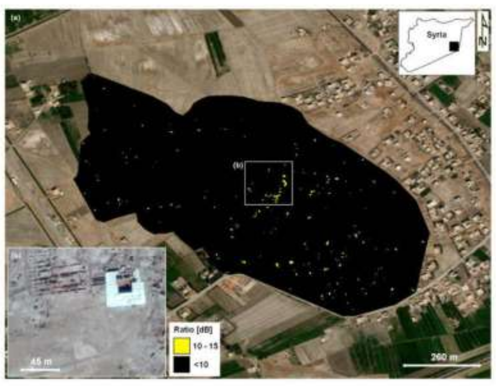
Spectral and topographic analysis of Tell Abu Tasah (single mound with mud-brick architecture) by integrating: (a) Google Earth (© 2019 Maxar Technologies); (b) Sentinel-2 multispectral image; (c) COSMO-SkyMed sigma nought (σ^0) image; (d) COSMO-SkyMed DEM.

Condition assessment

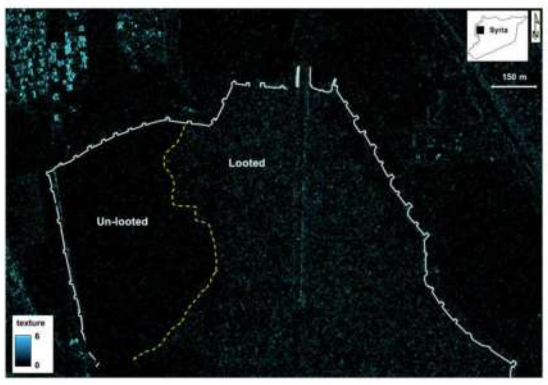
Archive images are required to substantiate events of damage that have been allegedly reported or to assess the impact of known events. For example, the archaeological site of Mari (Tell Hariri) in Syria was extensively looted between 2011 and 2014. The walls in the religious precinct in the south-eastern part of the Royal Palace were levelled and airstrikes damaged the covered temple.

By ratioing the radar backscatter of the available archive StripMap image (10/03/2010, prior to the civil war) with a new image (10/08/2018) collected with the same acquisition parameters, we identified clusters of ratio values higher than 10 dB, matching with the areas where looting and damage were reported.

However, in absence of intermediate COSMO-SkyMed images between 2010 and 2018, the change patterns are all summed together and cannot be temporally distinguished.



(a) Change detection map of the site of Mari (Tell Hariri) in Syria, obtained by ratioing a pair of COSMO-SkyMed StripMap Himage images acquired on 10/03/2010 (prior to the civil war) and 10/08/2018 in descending mode, using an incidence angle of 40°. (b) The inset shows the covered temple of the Royal Palace, where a pattern of increased backscatter is clearly observed.



Texture map of the northern sector of Apamea (Syria) extracted from a COSMO-SkyMed Enhanced Spotlight image. Looted areas are clearly identified.

An effective single image-based method to identify landscape disturbance is SAR texture extraction. In Apamea, texture marks the separation between looted areas and un-looted ground, based on the sharp spatial variations in backscatter occurring in the presence of looting holes.

Environmental monitoring

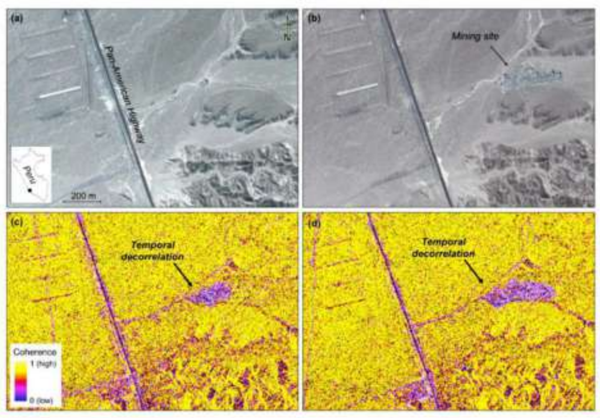
By ratioing the radar backscatter between pairs of COSMO-SkyMed scenes from a long time series, we track changes on a regular basis to assess anthropogenic impact on the cultural landscape of the Nasca Lines, Peru.

In the valley of Rio Ingenio, COSMO-SkyMed change detection maps allow the identification of crops where cultivation and irrigation activities are ongoing.

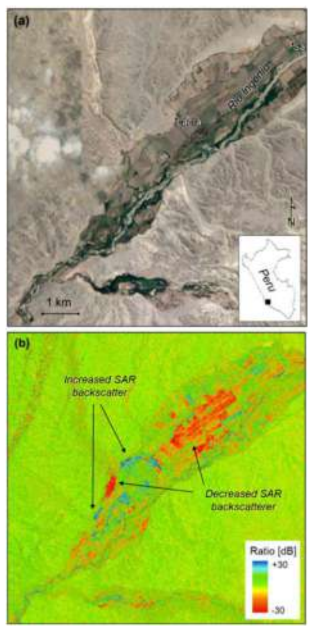
Because the constellation is tasked to acquire StripMap images over the Nasca Lines at a regular temporal sampling of 16 days, we are able to detect areas of landscape disturbance that may not have been already known.

The bottom figure shows an incident of modern mining that was first identified east of the Pan-American Highway based on the computation of interferometric coherence (i.e. the degree of correlation between phase and amplitude information) between 31/07/2013 and 16/06/2014.

The subsequent expansion was clearly picked up one year after, between 10/07/2014 and 05/07/2015.



(a) The 2013 vs. (b) the 2016 satellite view of a desert area near Palpa (Peru), where a mining site was developed east of the Pan-American Highway (Google Earth images © 2018 DigitalGlobe); and InSAR coherence from two pairs of COSMO-SkyMed StripMap scenes: (c) 31/07/2013–16/06/2014 and (d) 10/07/2014–05/07/2015 (5 and 30 m perpendicular baseline, respectively).



Changes in agricultural fields along the valley of Rio Ingenio, near the town of Lacra in Peru as seen in (a) Google Earth image © 2018 DigitalGlobe) and (b) SAR ratio map between COSMO-SkyMed StripMap scenes acquired on 03/06/2018 and 18/07/2017.

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TAPETE D., CIGNA F. 2019. **COSMO-SkyMed SAR for Detection and Monitoring of Archaeological and Cultural Heritage Sites.** *Remote Sensing*, 11 (11), 1326; doi:10.3390/rs11111326

Acknowledgements

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Recent literature and projects using COSMO-SkyMed data for science and applied research suggest an increasing interest in these data for archaeology. The use-cases developed by ASI's Scientific Research Unit confirm that COSMO-SkyMed can support activities of archaeological prospection, topographical surveying, condition assessment and environmental monitoring. In this regard, the growing image catalogue over heritage sites is a valuable asset.