Thermal prospecting on vegetation

by Ulrich Kiesow (archaeoflug)

Abstract

In *summer 2005, archaeoflug carried out a series of flights with the aim* of *testing a* ***new method of archaeological prospecting*** *for its ranges of application*. With a thermal image camera a*erial videos of potential negative crop marks were taken and evaluated. The series of flights confirmed the assumption of the author that the development of a negative crop mark is accompanied by an increase of temperature of the vegetation concerned. Archaeoflug has succeeded in proving the existence of "warm crop marks" which can be seen before and during the emergence of negative crop marks. The following article explains the method of thermal prospecting as an additional method of aerial archaeological photography.*

Contents page

I. Thermal prospecting

a. Bare soils

Until now thermal prospecting has been carried out predominantly on bare soils. Since the soil reacts strongly delayed, long meteorological warming or cooling phases are necessary. The measurable temperature differences are low. Medieval field boundaries, ditch and embankment structures have been thermally documented[1]. Until now, detailed architectural structures have not been detected.

b. Cold crop marks

Irwin Scollar[1] points out further possibilities of thermal prospecting in his researches. He describes *cold crop marks* of square embankment structures of prehistoric origin. As a cause for these potential *positive crop marks* he suspects an increase of the water evaporation (evapotranspiration) during the growth phase.

c. Warm crop marks

Until now, potential negative crop marks, however, were not examined. Archaeoflug assumes that potential negative crop marks lead to warm crop marks. As a cause Archaeoflug suspects a decrease of the water evaporation (evapotranspiration) and consequently a warming of the plant during the growth phase.

II. Emergence and characteristics of warm crop marks

a. Emergence

Plants regulate their temperature by water transpiration. Water shortage, leads to a restricted water evaporation.

If at the same time warmth is supplied to the plant from the outside (sun radiation, increasing air temperature), then the plant can no longer prevent its temperature from rising. A warm crop mark is produced. Three stages of development of warm crop marks are possible.

1. At the beginning of water shortage the temperature of the plant rises. A warm crop mark of 1st order appears. No classic crop mark is recognizable yet.

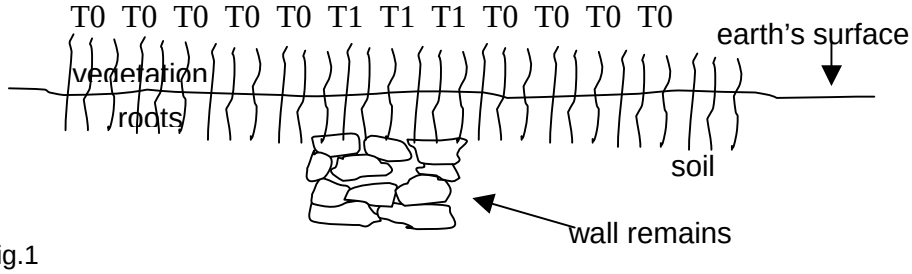


Fig.1
beginning water shortage, temperature rises, warm crop mark of 1st Order

2. As long as the vegetation is still green and the water shortage continues, the buried structure becomes visible to the eye as a pale brown crop mark. A volatile classic negative crop mark and warm crop mark of 2nd order appears.
In the more mature, browner condition this brightening is no longer perceptible with the eye, however it is still thermally visible.

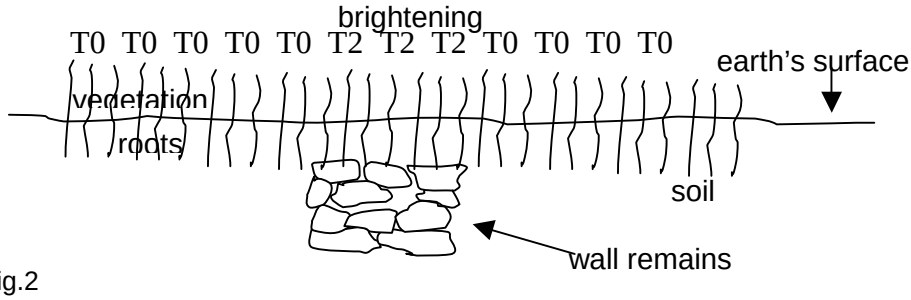


Fig.2
Continuous water shortage, temperature rises, warm crop mark of 2nd Order

3. If the water shortage persists, the volatile classic negative crop mark will wither and become fixed. A warm crop mark of 3rd order appears.

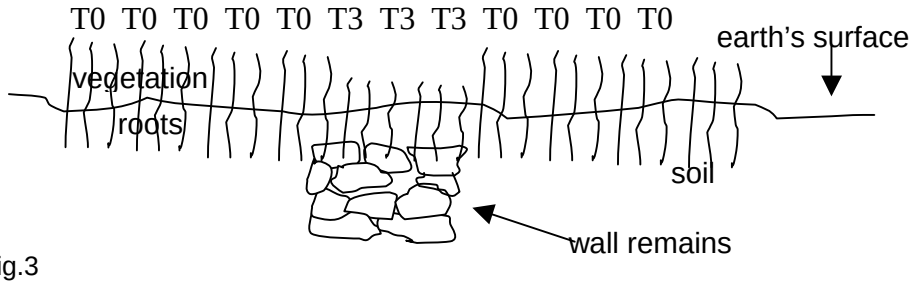


Fig.3
Continuous water shortage, temperature rises, withering, warm crop mark of 3rd Order

At full maturity no more evaporation takes place. Temperature differences can only arise from shading.
The stages of development 1 and 2 are reversible when water shortage disappears.
The following table shows the relationship between classical and warm crop marks

water shortage	tem-perature rise	crop mark visibility	rever-sible	optically pro-spectable	thermally pro-spectable	classifi-cation
begins	yes	no visible crop mark	yes	no	yes	1st order
con-tinues	yes	visible only when vegetation is green	yes	on green vegetation	yes	2nd order
con-tinues	yes	visible withering crop mark	no	yes	yes	3rd order

Tab.1 Classification of warm crop marks

b. Characteristics
Warm crop marks appear depending on the warmth supplied to them. They are therefore volatile and recurrent. Provided that there is sufficient water shortage short warming phases will let the plant temperature rise significantly.
The measurable temperature differences go up to approx. 2.5°centigrade.
The representation of detailed buried structures is possible.
Low humidity supports evaporation and the development of the crop mark. Strong air movement leads to a greater removal of warmth and has a weakening effect.
Since a short water shortage appears more frequently than a long one, warm crop marks appear more frequently than classic crop marks.

III. Application potential of the method

a. Enlargement of the prospecting-time-period

Warm crop marks appear before and together with classic negative crop marks. Through this the time-period in which a buried structure is detectable increases. Hidden structures in the ground can thus be prospected *within a longer period of time*

b. Detection of new archaeological sites

A hidden structure which for meteorological reasons (a too short dry period) cannot be discerned as a classic negative crop mark can be documented by thermal prospecting as a warm crop mark of 1st order. The method therefore permits the detection of unknown archaeological structures.

IV. Technique of thermal Prospecting

a. Camera

The camera used, AGEMA Thermovision 400, weighs approx. 6 kg, has the size of a TV camera and produces a picture with a resolution of 140x140 pixels. A telephoto lens with a 7° angle is used. On the micro-light aircraft the passenger sitting behind the pilot operates it sideways. Oblique to almost vertical pictures can be taken. Newer camera models produce a resolution of 320x240 dpi, are smaller and lighter. At the moment, one-man prospecting by the pilot himself is not conceivable because of the low resolution and the continuously necessary readjustment of the camera.

b. Documentation

The picture produced by the thermal image camera is recorded by means of a digital video recorder in a video file. Post processing can produce single pictures from the recorded video file.
In addition 70 thermally analysable pictures can be stored on a built-in 31/2 inches diskette drive.
Similar to rules for the interpretation of aerial pictures: In the case of doubt it is not a buried archaeological site.

c. Flying

Flying over a specific object
When prospecting thermally, the concerned surface is observed on the camera screen or through the eyepiece.
The current picture produced by the camera is observed. This observation type is suitable for aiming at specific targets such as known archaeological sites and suspected settlement locations.
Because of the low camera resolution, low altitudes have to be flown. The target is typically orbited repeatedly with decreasing altitude. Through this, sun reflection can be better distinguished from thermal radiation. At a lower altitude the precision of detail increases. When envisaging the target, natural or artificial points of orientation are advisable in the area. Preferably a light and agile aircraft should be used.

Flying without a specific target
At present, thermal prospecting of an extensive area, with the aim of detecting new sites or structures like in classic aerial photography, is not possible.
This can only be achieved by systematically prospecting a predefined limited grid and then evaluating the produced data on the ground.
As this kind of prospecting is flown at a higher altitude, a camera with a high resolution has to be used.
Possibly a combination of a helmet camera and video glasses could produce a situation similar to classical aerial photography.

V. The summer-2005 project

a. Project aims

Aims of the examination of warm crop marks were:
- the proof of their existence
- the comparison with the classic crop mark
- the analysis of the meteorological influences

b. The examination object

A roman villa was chosen as the object of examination.
Parts of the villa had been excavated and documented in the sixties and after that turned back into arable land. (Fig.4)
Since 2003 aerial photos have been taken by archaeoflug, which show the part of the villa, which has already been excavated. (Fig.5)
The documented known part makes it possible to interpret the thermal videos correctly by comparing them with the existing plans and aerial photos. The unknown part of the villa represents a new archaeological site still to be prospected.

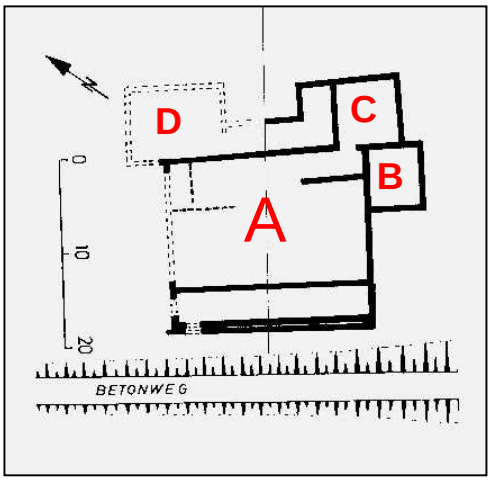


Fig.4

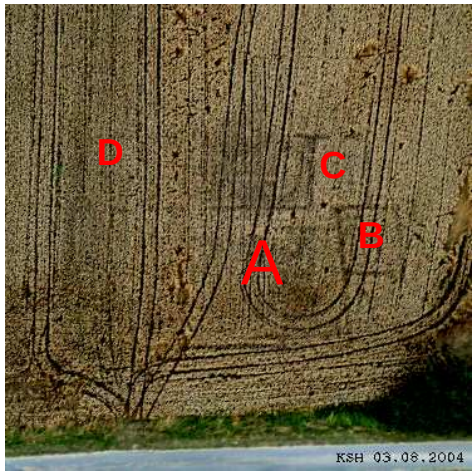


Fig.5

c. Examination process

Between June 23rd and July 23rd 2005 archaeoflug carried out ten thermal prospectings of the object. (Fig. 6)
Tied into the professional and private situation of the team, the diurnal moment of the flights arose more or less spontaneously and lacks a desirable wider diurnal spread and regularity.

Fig. 6

	JUNI								JULI																					
Datum	23	24	25	26	27	28	29	30	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Flug Nr.	1	2															3		4	5	6	7			8					9	10
Uhrzeit	19	17															19		19	18	19	19			19					17	12

d. Meteorological conditions

The meteorological conditions (Fig.7) were provided by Agrowetter.de and contain:

- Calculated soil temperatures in different depths down to 1 meter
- sunshine duration
- air temperature
- air humidity ..... in Saarbrücken/Ensheim.

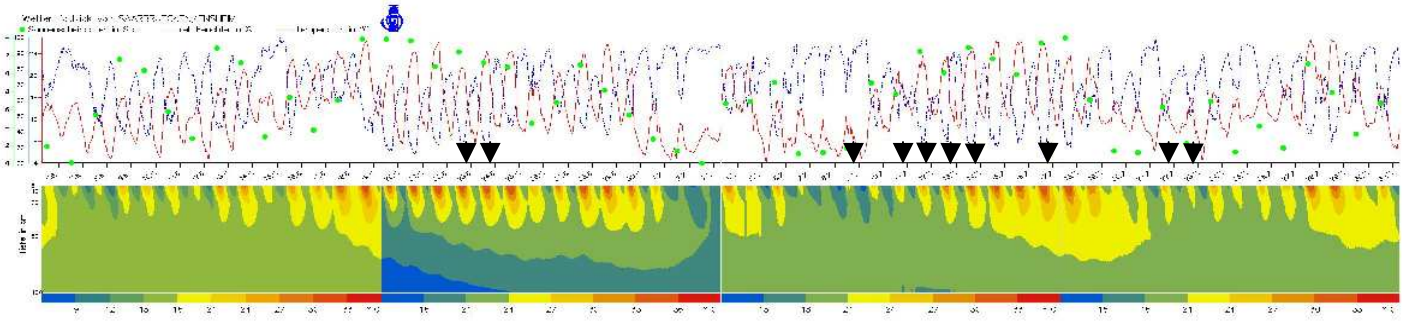


Fig.7

Due to the distance of about 30 km between the target and the place of measurement, the data only partly corresponds to the actual conditions on the site.

The more exact canopy temperatures of the cornfield result from the data of the camera.

The black arrows mark the individual time of the flights.

It has to be taken into account that in the first and second 14-day representation of the soil temperature the colours of the temperatures differ from each other. At the third and fourth representation the temperature colours correspond, are upgraded, however, compared with the first two parts of the data.

e. Documentation

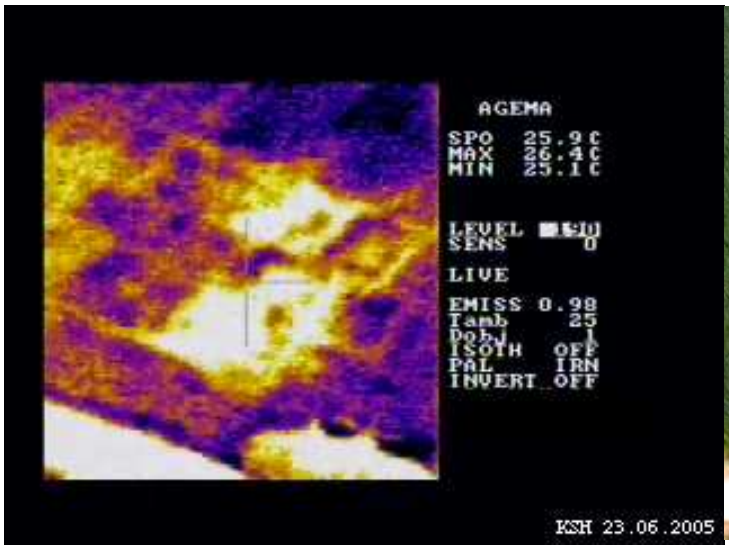
All prospecting results are documented in a comparison of thermal picture and aerial photo with the necessary meteorological data in a chronological order below.

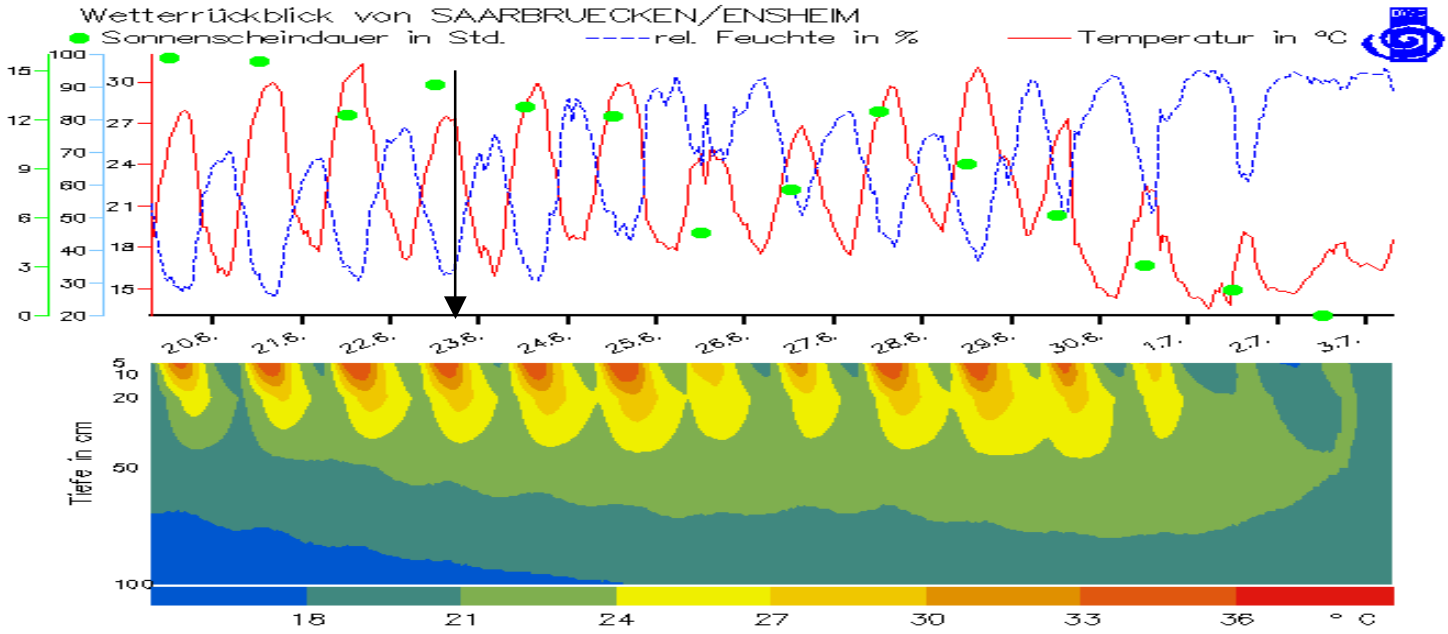
In addition the analysis of the meteorological conditions, accompanied by a comparative image analysis is carried out.

The thermal pictures were taken from the most informative parts of the thermo videos.

Because they are moving pictures, the thermo videos are more impressive to look at and contain more information than the single thermal pictures.

1st thermal prospecting on vegetation
Date: 2005-06-23 Time: approx. 19.00h
Documents: Thermo video-picture / aerial photo / meteorological information from 05-06-20 to 05-07-03

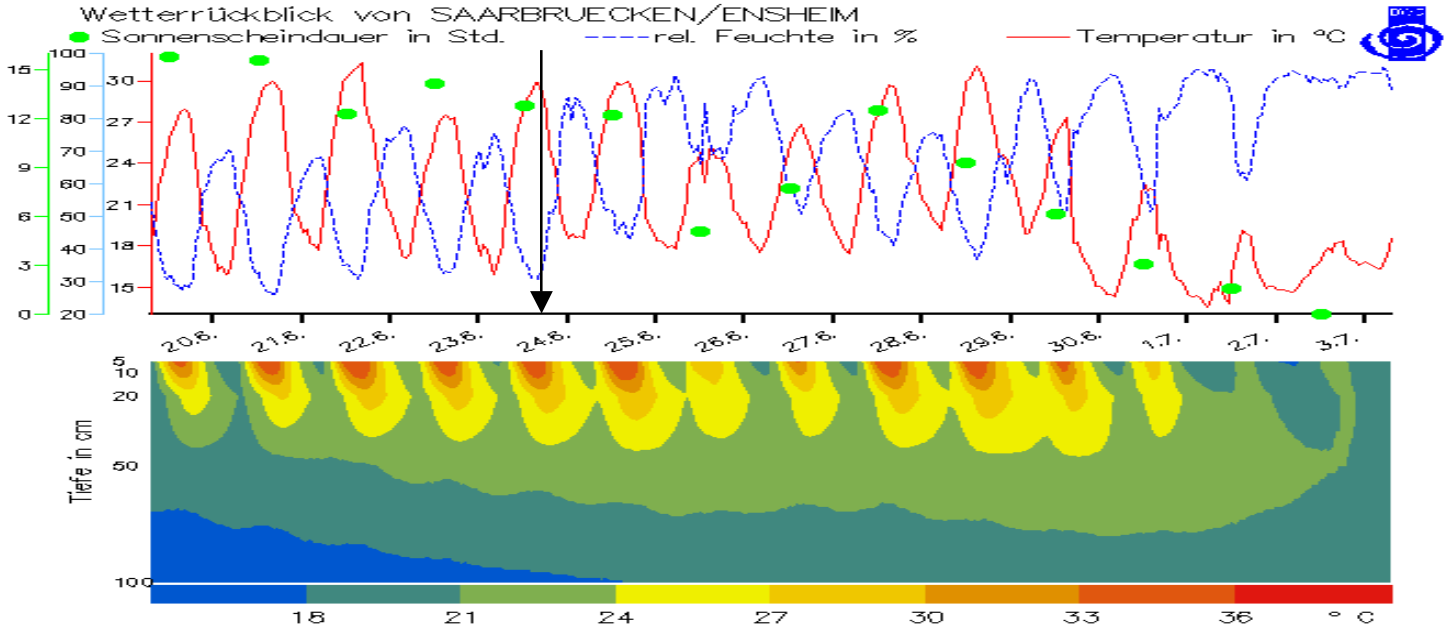




Meteorological conditions
- 7-day period of increasing warmth, at first, due to increasing air temperatures from 06.15, then from 19.06 due to long sunshine duration between 12 and 15 hours
- air temperature in SB-Ensheim at time of prospecting: 27°degrees Celsius
- air humidity in SB-Ensheim at time of prospecting: 17%
- canopy temperature: 25.1°degrees Celsius to 26.4 °degrees Celsius

Comparative image analysis
Thermal image: The extension, shape and structure of the object are clearly recognizable in detail. The known part of the object shows a warm crop mark of 2nd or 3rd order, the unknown part shows a warm crop mark of 1st order.
Aerial picture: The known part is clearly visible, the unknown part can be suspected, however it is incomplete and diffuse. The colour of canopy is dark-green.
The thermal image is clearly superior to the aerial photo. It shows all information of the aerial photo and furthermore additional detailed structures. These can not be seen in the aerial photo, or are only vaguely recognizable.

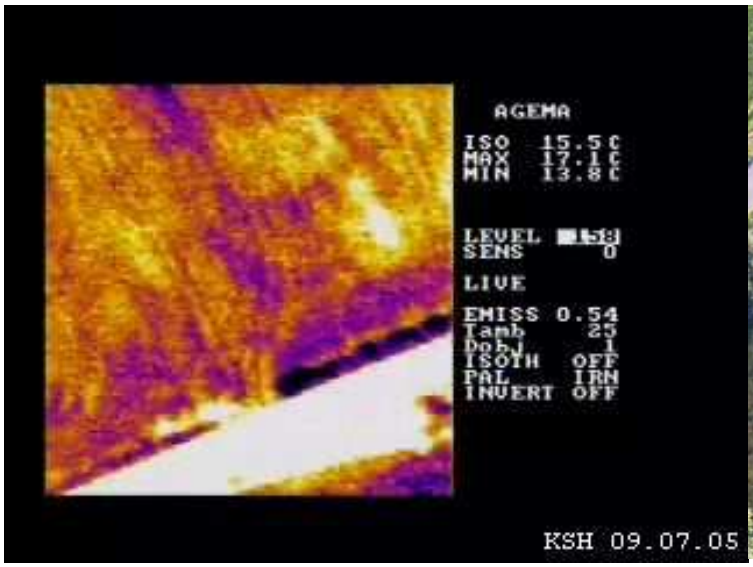
2nd thermal prospecting on vegetation
Date: 2005-06-23 Time: approx. 17.00h
Documents: Thermo video-picture / aerial photo / meteorological information from 05-06-20 to 05-07-03

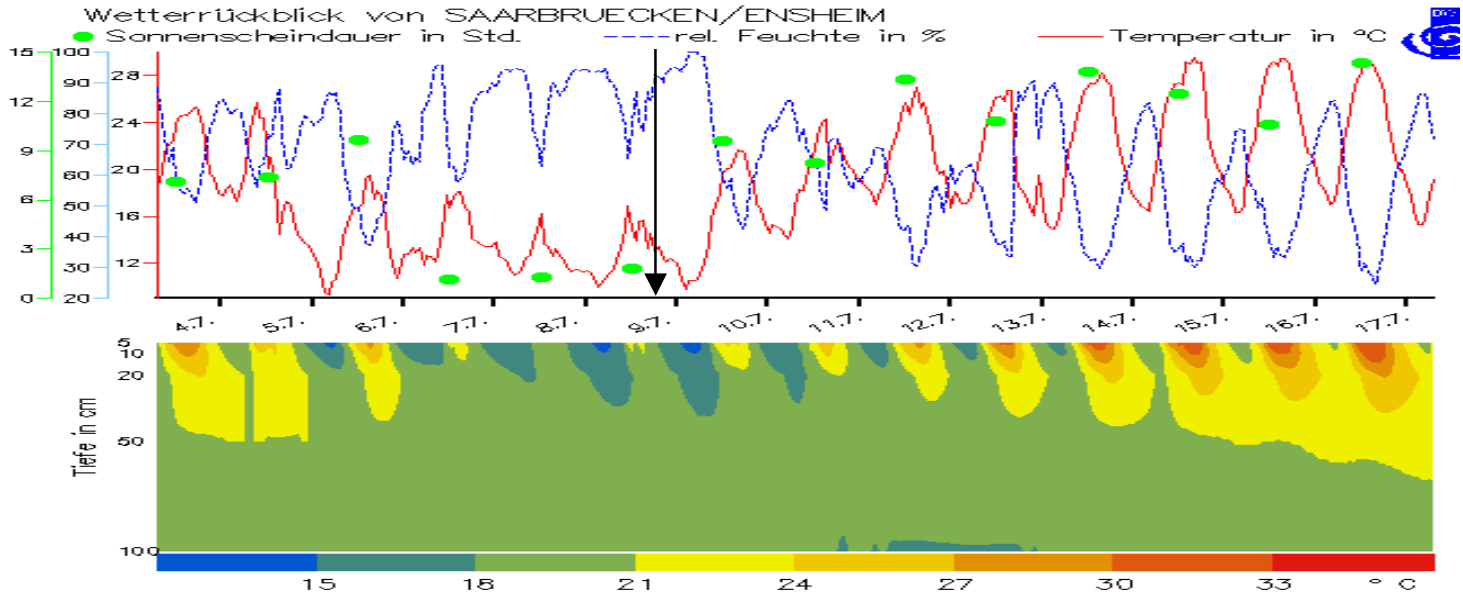


Meteorological conditions
- 8-day period of increasing warmth, at first, due to increasing air temperatures from 06-15, then from 19.06 due to long sunshine duration between 12 and 15 hours
- air temperature in SB-Ensheim at time of prospecting: 29°degrees Celsius
- air humidity in SB-Ensheim at time of prospecting: 16%
- canopy temperature: 24.0°degrees Celsius to 25.4 °degrees Celsius

Comparative image analysis
Thermal image: The extension, shape and structure of the object are clearly recognizable in detail. (not quite as well as on the day before)
Aerial photo: The known part is clearly visible, the unknown part can be suspected, however it is incomplete and diffuse. (slightly better than on the day before) The colour of canopy is green.
The thermal image is superior to the aerial photo. It shows all information of the aerial photo and furthermore additional detailed structures. These can not be seen in the aerial photo, or are only vaguely recognizable.
In comparison to the preceding day the amount of information in the thermal image has slightly diminished.
The information in the aerial photo has slightly increased

3rd thermal prospecting on vegetation
Date: 2005-07-09 Time: approx. 19.00h
Documents: Thermo video-picture / aerial photo / meteorological information from 05-07-04 to 05-07-17



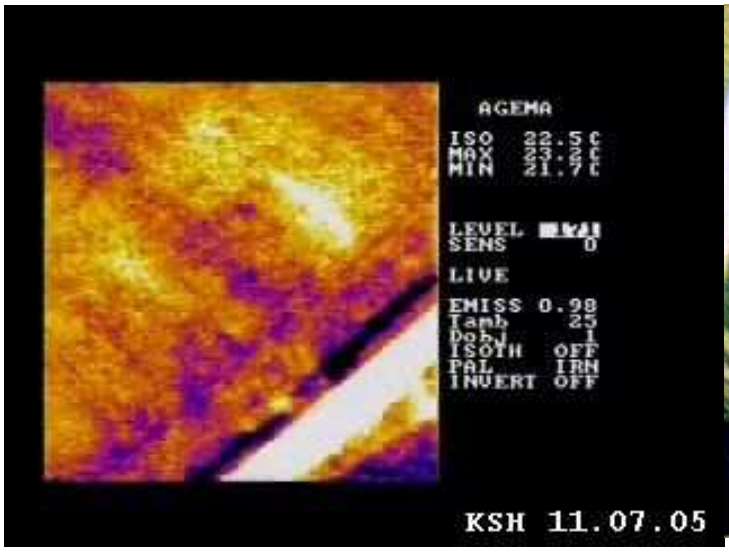


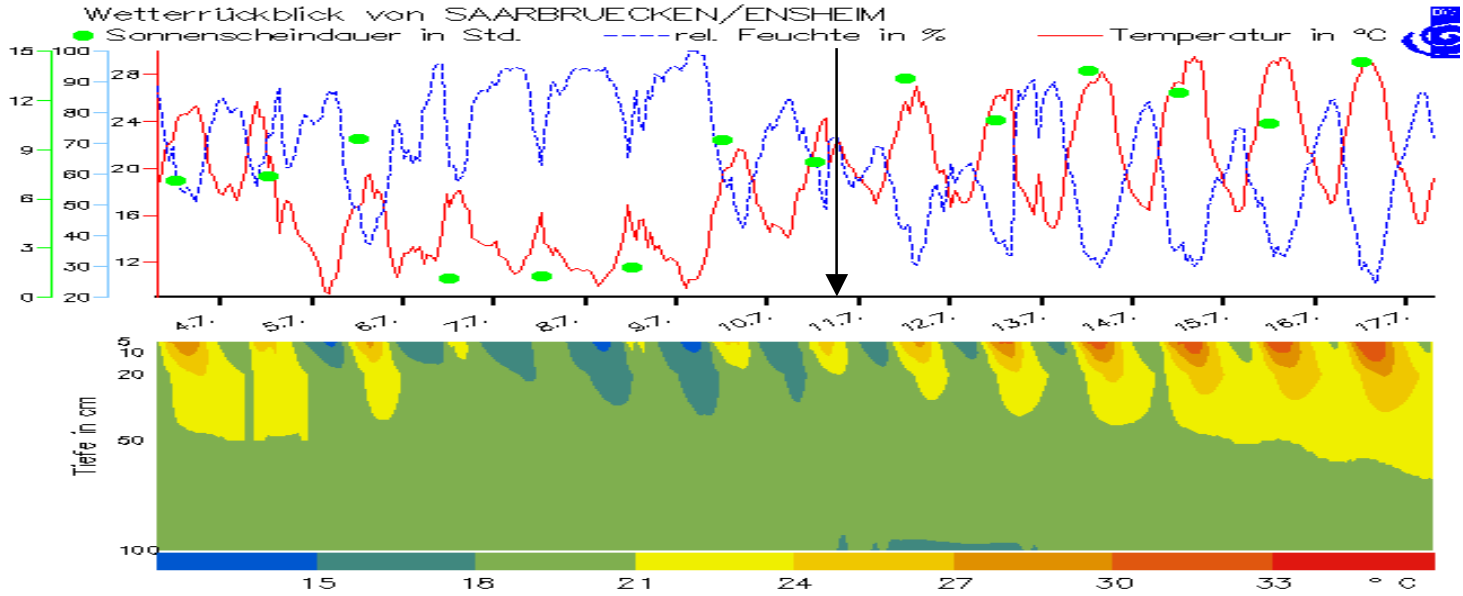
Meteorological conditions
- 11-day period of minimal solar radiation, daytime maximum temperatures sink from 30°degrees Celsius to 15°degrees Celsius. Three days of maximum air humi dity over 90% (rainy days)
- air temperature in SB-Ensheim at time of prospecting: 14°degrees Celsius
- air humidity in SB-Ensheim at time of prospecting: 90%
- canopy temperature: 13.8°degrees Celsius to 17.1 °degrees Celsius

Comparative image analysis
Thermal image: The extension, shape and structure of the object are no longer recognizable
Only two parts of the object are interpretable as warm rectangular structures.
Aerial photo: The known part is clearly visible, the unknown part can be suspected, however it is incomplete and diffuse.

The colour of canopy is green-brown. The aerial photo is clearly superior to the thermal image. The thermal image has almost no more evaluative information.

4th thermal prospecting on vegetation
Date: 2005-07-11 Time: approx. 19.00h
Documents: Thermo video-picture / aerial photo / meteorological information from 05-07-04 to 05-07-17



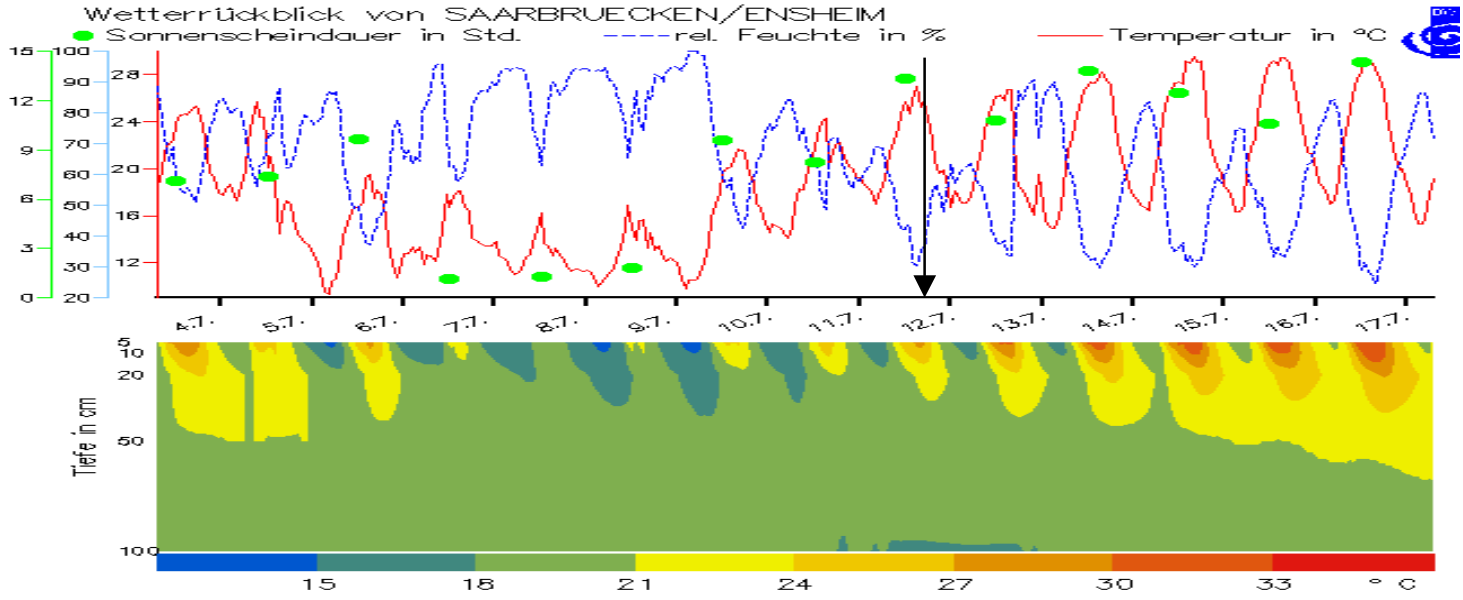


Meteorological conditions
-Beginning of a phase of increasing warmth after two days of increasing solar radiation.
Daytime maximum temperatures rise from 16℃elsius t o 23℃elsius. Air humidity decreases from 90% to 60%.
- air temperature in SB-Ensheim at time of prospecting: 22° degrees Celsius
- air humidity in SB-Ensheim at time of prospecting: 70%
- canopy temperature: 21,7° degrees Celsius to 23,2 ° degrees Celsius

Comparative image analysis
Thermal image: The extension, shape and structure of the object are no longer recognizable
The two warm rectangular structures interpretable as parts of the buried object appear less clear.
Aerial photo: The known part is clearly visible, the unknown part can be suspected, however it is incomplete and diffuse.
The colour of canopy is green-brown.

The aerial photo is clearly superior to the thermal image. The thermal image still has almost no evaluative information.

5th thermal prospecting on vegetation
Date: 2005-07-12 Time: approx. 18.00h
Documents: Thermo video-picture / aerial photo / meteorological information from 05-07-04 to 05-07-17

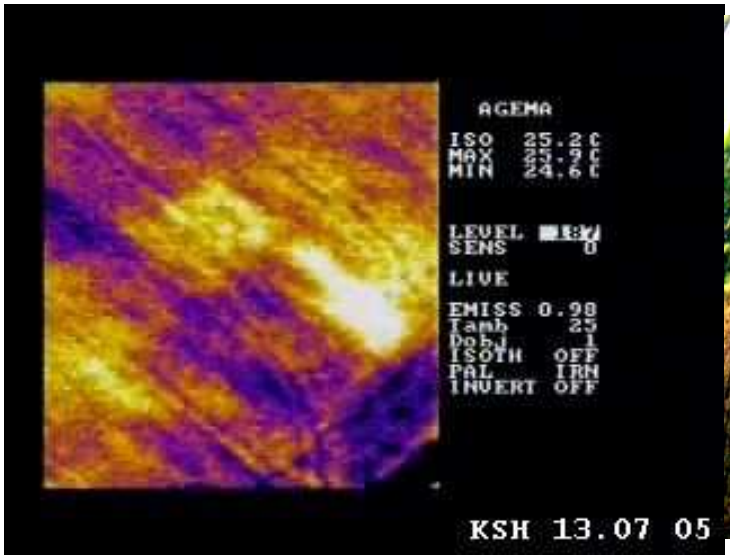


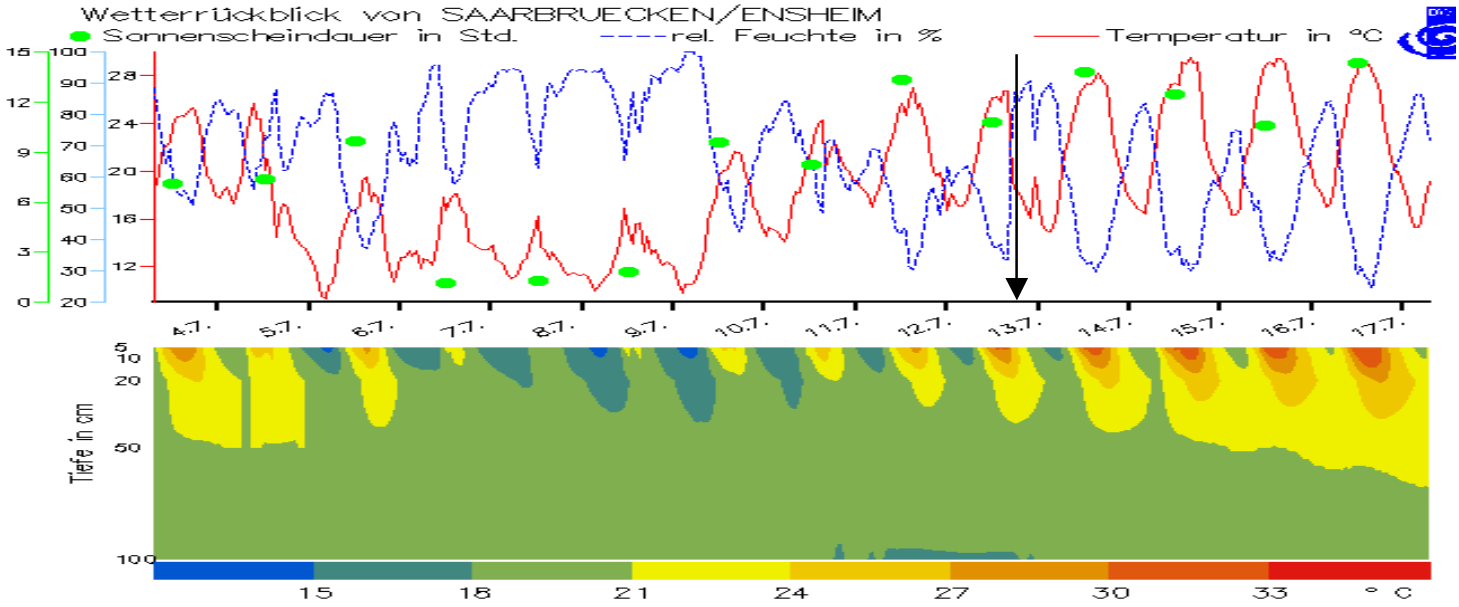
Meteorological conditions
-Continuing phase of increasing warmth after three days of increasing solar radiation.
Daytime maximum temperatures continue to rise. Air humidity is continuously decreasing.
- air temperature in SB-Ensheim at time of prospecting: 26° degrees Celsius
- air humidity in SB-Ensheim at time of prospecting: 40%
- canopy temperature: 22,3° degrees Celsius to 23,7 ° degrees Celsius

Comparative image analysis
Thermal image: The extension, shape and structure of the object are beginning to be recognizable again, however diffuse.
Aerial photo: The known part is clearly visible, the unknown part can be suspected, however it is incomplete and diffuse.
The colour of canopy appears more brown than green.

The information of the thermal image is again superior to the thermal image especially because it shows the unknown parts of the structure.

6th thermal prospecting on vegetation
Date: 2005-07-13 Time: approx. 19.00h
Documents: Thermo video-picture / aerial photo / meteorological information from 05-07-04 to 05-07-17





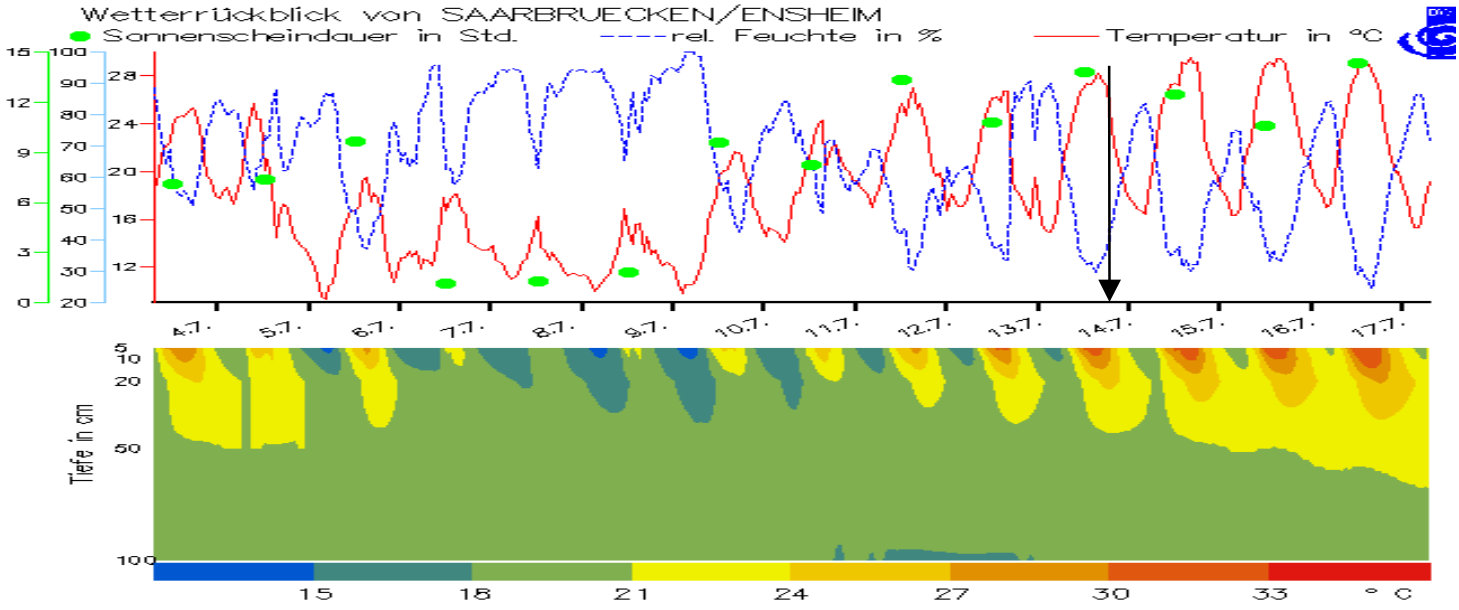
Meteorological conditions

-Stable phase of increasing warmth after four days of increasing solar radiation.
Daytime maximum temperatures continue to rise. Air humidity is continuously decreasing.
Presumably there were showers in SB-Ensheim.
- air temperature in SB-Ensheim at time of prospecting: 18°degrees Celsius
- air humidity in SB-Ensheim at time of prospecting: 85%
- canopy temperature: 24,6°degrees Celsius to 25,9 °degrees Celsius

Comparative image analysis

Thermal image: The extension, shape and structure of the object are recognizable again, however they are diffuse. More exact details can not be seen jet. Compared to the day before the contours are beginning to turn sharper.
Aerial photo: The known part is clearly visible, the unknown part can be suspected, however it is incomplete and diffuse.
The colour of canopy appears more brown than green.
The information of the thermal image is again superior to the thermal image especially because it shows the unknown parts of the structure. This is better visible in the video.

7th thermal prospecting on vegetation
Date: 2005-07-14 Time: approx. 19.00h
Documents: Thermo video-picture / aerial photo / meteorological information from 05-07-04 to 05-07-17



Meteorological conditions

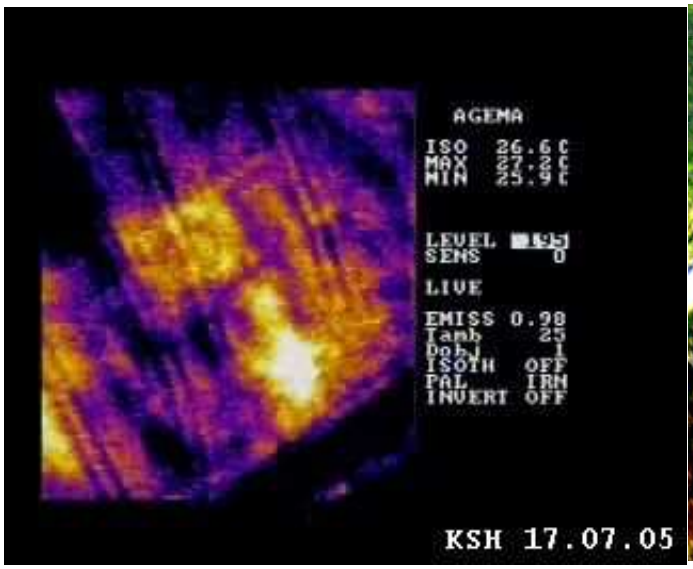
-Stable phase of increasing warmth after five days of increasing solar radiation.
Daytime maximum temperatures continue to rise. Air humidity is continuously decreasing.
- air temperature in SB-Ensheim at time of prospecting: 26° degrees Celsius
- air humidity in SB-Ensheim at time of prospecting: 40%
- Canopy temperature: 25,9° degrees Celsius to 27,2 ° degrees Celsius

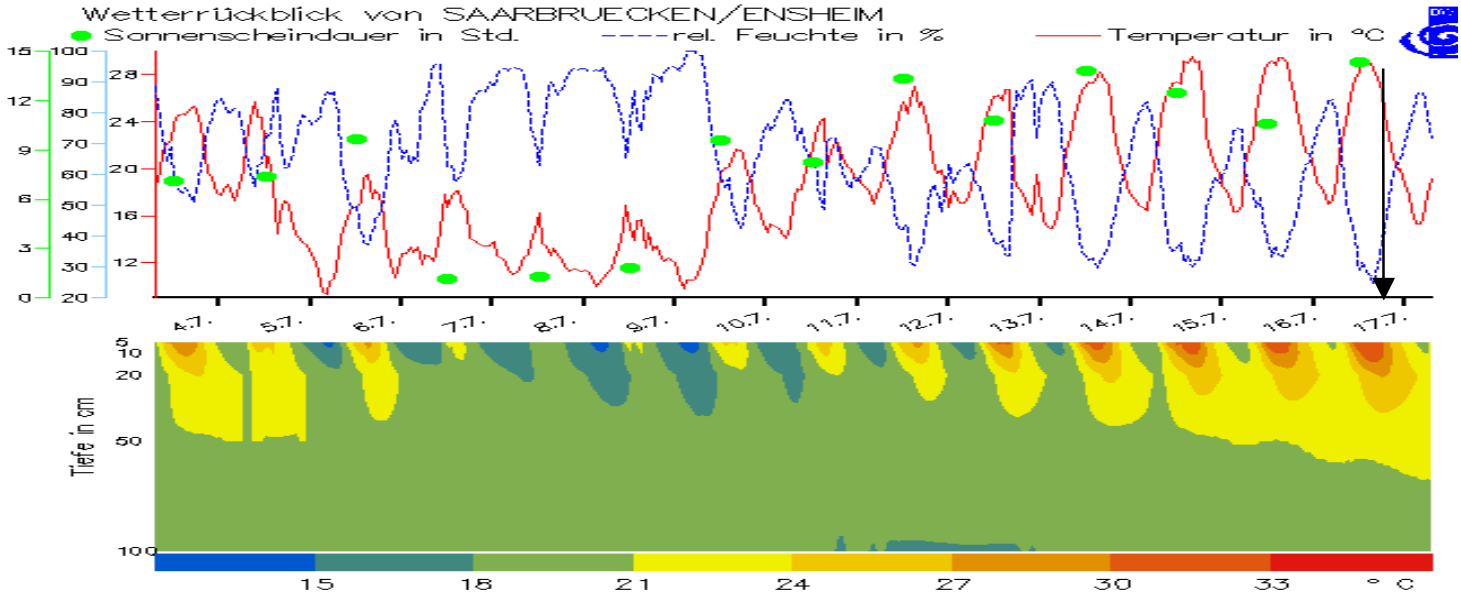
Comparative image analysis

Thermal image: The extension, shape and structure of the object are better recognizable again. More exact details can be seen too. (pieces of wall in structure B)
Aerial photo: The known part is clearly visible, the unknown part can be suspected, however it is incomplete and diffuse.
The colour of canopy appears almost completely brown.

The information of the thermal image is again superior to the thermal image especially because it shows the unknown parts of the structure. Particularly notable in this image is the very scarce scattering of stones in the middle part of the villa.

8th thermal prospecting on vegetation
Date: 2005-07-17 Time: approx. 19.00h
Documents: Thermo video-picture / aerial photo / meteorological information from 05-07-04 to 05-07-17





Meteorological conditions

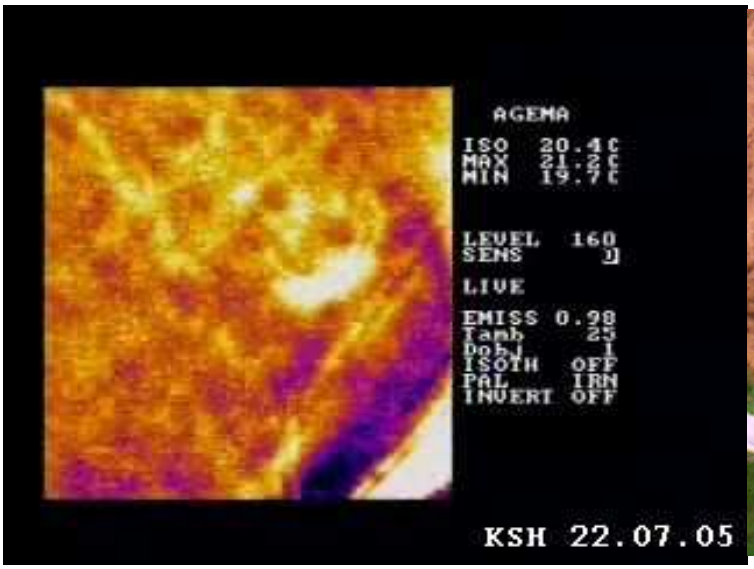
-Stable phase of increasing warmth after eight days of increasing solar radiation.
High and stable daytime maximum temperatures. Air humidity is continuously decreasing.
- air temperature in SB-Ensheim at time of prospecting: 26°degrees Celsius
- air humidity in SB-Ensheim at time of prospecting: 40%
- Canopy temperature: 25,9°degrees Celsius to 27,2 °degrees Celsius

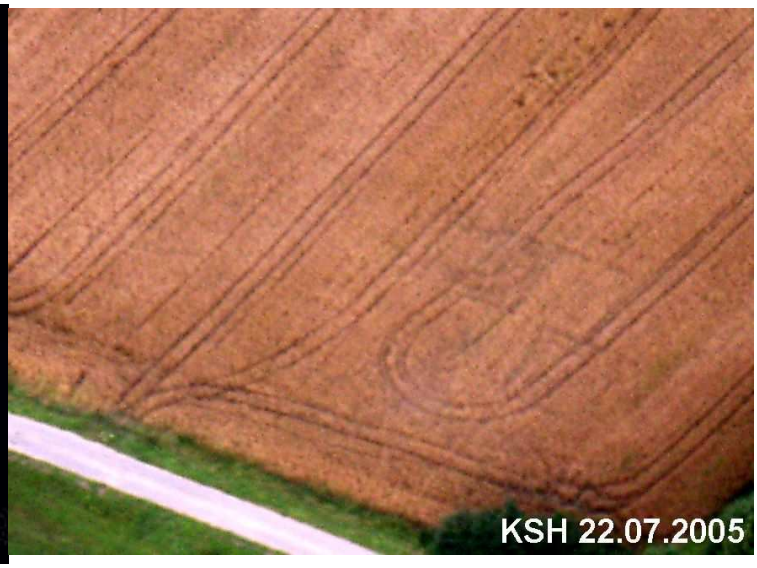
Comparative image analysis

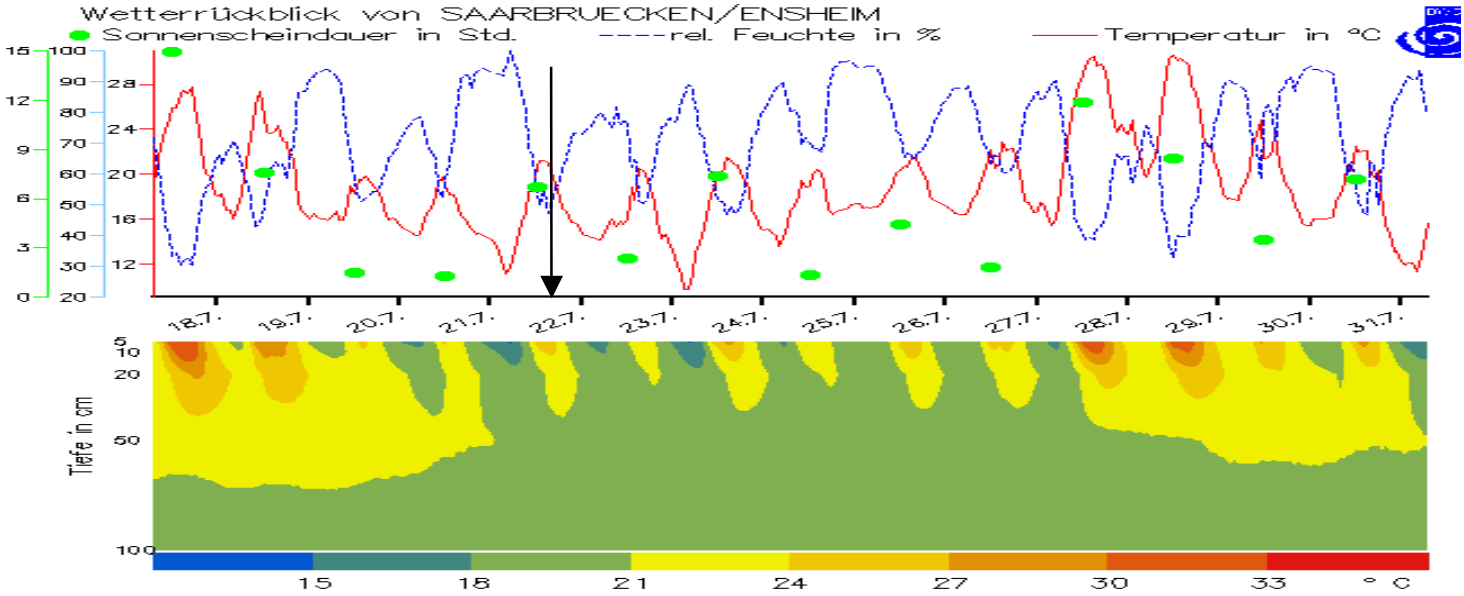
Thermal image: The extension, shape and structure of the object are increasingly recognizable. More exact details can be seen too. (pieces of wall in structure B and C)
Aerial photo: The known part is clearly visible, the unknown part can be suspected, however it is incomplete and diffuse.
The colour of canopy is brown.

The information of the thermal image is again superior to the aerial photo. It shows all the information of the aerial photo and detailed additional structures, which can not or only vaguely be seen in the aerial photo.

9th thermal prospecting on vegetation
Date: 2005-07-22 Time: approx. 17.00h
Documents: Thermo video-picture / aerial photo / meteorological information from 05-07-18 to 05-07-31







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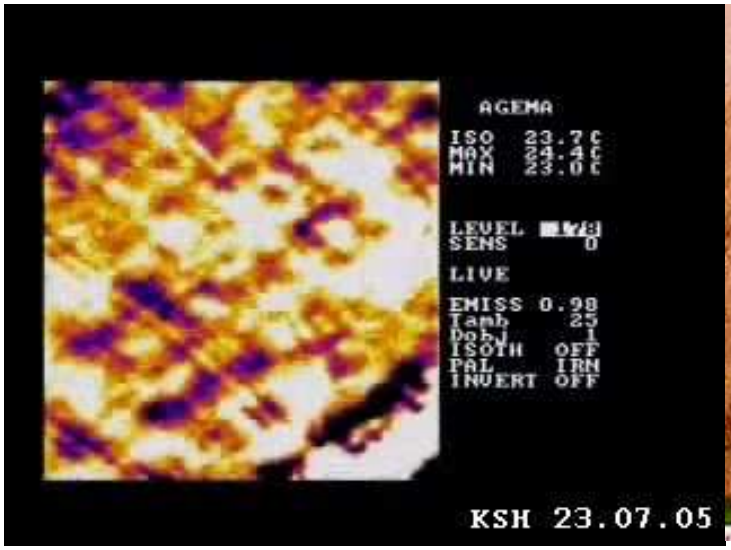
Meteorological conditions

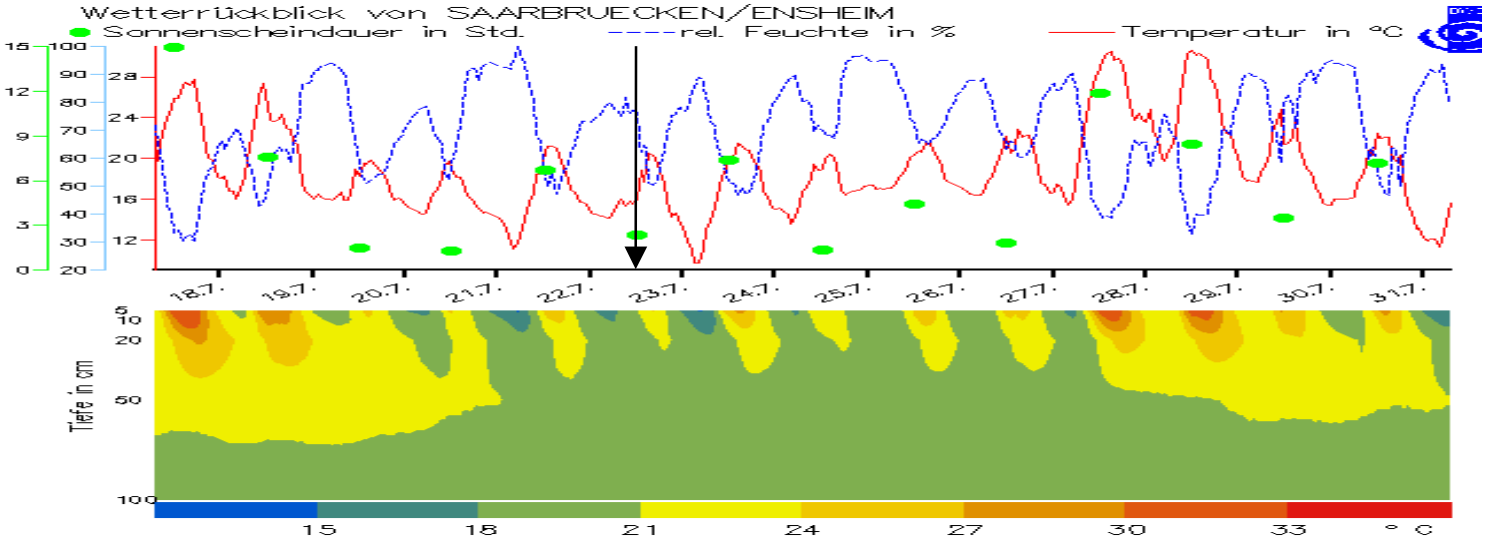
After four days of cooling with partly very low solar radiation the air temperature has fallen considerably and the humidity has risen.
- air temperature in SB-Ensheim at time of prospecting: 20°degrees Celsius
- air humidity in SB-Ensheim at time of prospecting: 55%
- Canopy temperature: 19,7°degrees Celsius to 21,2 °degrees Celsius

Comparative image analysis

Thermal image: Neither the extension, nor shape and structure of the object are recognizable. The object can hardly be identified. Only the continuously warmer structure of part A still stands out.
Aerial photo: The known part is clearly visible, the unknown part can be suspected, however it is incomplete and diffuse.
The colour of canopy is light-brown.
The thermal image is inferior to the aerial photo again. Except for the first two flights the information of the aerial photo is basically stable and limited to the known southern part of the villa.

10th thermal prospecting on vegetation
Date: 2005-07-23 Time: approx. 12.00h
Documents: Thermo video-picture / aerial photo / meteorological information from 05-07-18 to 05-07-31





Meteorological conditions

After five days of cooling with partly very low solar radiation the air temperature has fallen considerably and the humidity has risen. The canopy temperature shows that the weather is better at the prospecting site.
- air temperature in SB-Ensheim at time of prospecting: 17° degrees Celsius
- air humidity in SB-Ensheim at time of prospecting: 65%
- Canopy temperature: 23,0° degrees Celsius to 24,4 ° degrees Celsius

Comparative image analysis

Thermal image: Due to the early time of flight, the presentation of the object is unfamiliar. At second glance however at least the A-, B-, and C-parts of the object can be recognized. The middle part with only scarce scattering of stones can be seen too.
Aerial photo: The known part is clearly visible, the unknown part can be suspected, however it is incomplete and diffuse.
The colour of canopy is light-brown.

The thermal image is inferior to the aerial photo. It becomes interpretable only together with the already provided information.

VI. Results

a. Proof of the existence of warm crop marks

During the summer- 2005 project the existence of warm crop marks could be definitively proved over a period of one month. 10 Thermo videos of different quality were taken.
The first thermal prospectings on the 23rd and 24th of July 2005 show warm crop marks of first, second and third Order.
On June 23rd the unknown northwest area of the villa is not jet definitively recognizable in the aerial photo and therefore has to be classified as a warm crop mark of 1st Order. One day later the new structure can be vaguely suspected in the aerial photo and therefore has to be classified as a warm crop marks of 2nd order in the thermal image.
The already known structures of the southeast area can be classified as warm crop marks of 2nd and 3rd order. Here the southern part of the structure A and structures B and C have already reached an irreversible condition of 3rd order. The structure D and the northern part of structure A are probably still reversible and therefore have to be classified as warm crop marks of 2nd order.
In the further process of the project some wall-structures of the northwest range running in north south direction develop into warm crop marks of 3rd order. The predominant part of the northwest range remains however reversible and only recognizable as warm crop mark of 2nd and 1st order. (see Fig. 9)
During the entire project temperature differences from shading are visible only as tractor-tracks.

b. Comparison with the classic crop mark

Comparing thermal image and aerial photo leads to differing results.
While the thermal images 1, 2, 5, 6, 7, 8 are superior to the aerial pictures, the thermal prospectings 3, 4, 9 and 10 show considerably less information.
The reason for this is that the prospectings 3, 4, 9 and 10 were carried out under thermally unfavourable conditions.
When prospecting thermally, the consideration of meteorological and flying conditions are of greater importance compared to the classic aerial photography.
Comparing the best results of both methods shows that thermal prospecting provides a greater amount of information than classic aerial photography.

- The volatile classic negative crop mark is only visible on green canopy up to a certain degree of maturity, whereas the warm crop mark reappears up to full maturity.
- Compared to the visibility of volatile classic crop marks, which appear together with warm crop marks of 2nd order, the latter can be seen significantly clearer.
- The thermal image can show warm crop marks of 1st order, which can not at all be seen, in the aerial photo.

c. Analysis of the meteorological conditions

Several consecutive warm and dry days in the phase of ripening provided the best results on June 23rd and 24th. Although on June 24th the conditions were theoretically better than on the day before, the thermal image turned out worse. This is presumably due to the 2 hours earlier flight. At the time of the later flight on day before less disturbing sun reflections were present. Consequently the best time for prospecting is during a short shading by clouds or at sunset. The best images would have had to be expected presumably in the evening of July 25th and 28th.

In the further course of the campaign, after a cooling phase, the thermal image becomes an informative document again starting on July 12th. The prospectings 5 to 8 fall into this warm period with high air temperatures and long sunshine duration.

Solar radiation

A preferably strong and long solar radiation will support the evaporation and the warming of the crop mark. To avoid disturbing reflections the object should not be exposed to direct sunlight at the time of flight.

Air temperature

A preferably high air temperature supports the evaporation and the warming of the crop mark.

Humidity

The lower the humidity, the higher the evaporation and the warming of the crop mark.

Air movement

Wind will lead to a weakening of the warm crop mark as the arising temperature differences are strongly diminished by the removal of warmth.

d. Analysis of the influence of flight-conditions

Phase of growth

The most informative images can be expected on the ripening, green vegetation, as the plants are “full of juice“ and react strongly when evaporation decreases. (similarly visible in the classic crop mark, see 2nd prospecting)

The riper the vegetation becomes, the less evaporation takes place and consequently the possible image contrast decreases.

Time of day

The experiences made in the campaign suggest, that prospecting in the late afternoon and evening promises the best results.

However further tests are necessary to confirm the following considerations:

- In the morning-time the humidity is high, solar radiation and the beginning of temperature rise are not jet sufficient to bring about a significant warming of the canopy.

- At noon the desirable full solar radiation is present, but leads to confusing reflections.
A temporary clouding however makes successful prospecting possible also at noon.

- In the afternoon the oblique sunrays only disturb in one line of sight and in the evening there are no disturbing reflections at all. The humidity is low, the air temperature is still high and the air movement dies down.

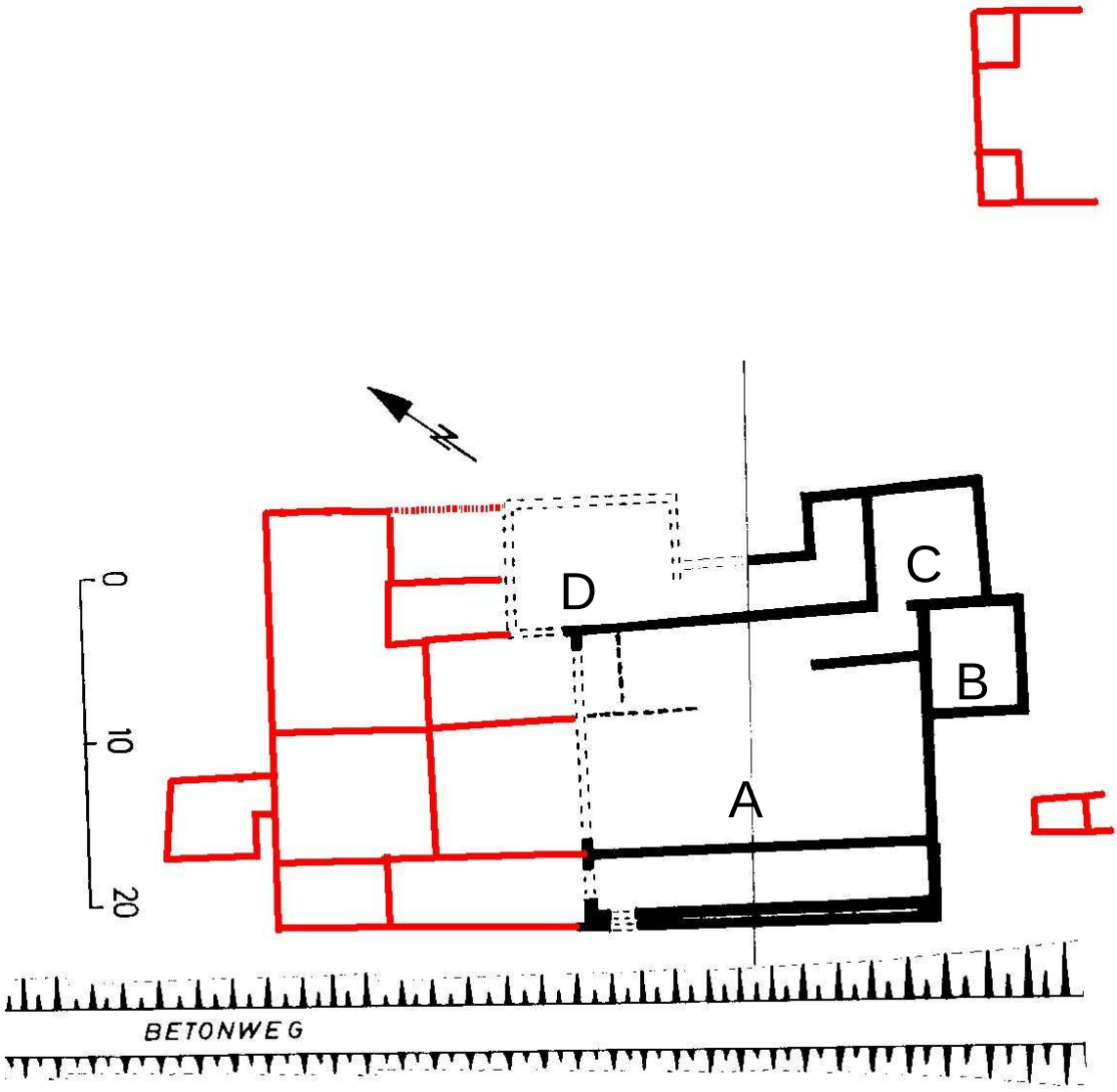


Fig.9
The prospecting target of the summer 2005 project
Roman villa: former excavation (black) and new prospecting results (red)

VII. Outlook

The summer-2005 project has rendered essential insights into thermal prospecting on vegetation
A continuation under consideration of the results achieved and with the aim of deepening and improving the application of the method is worth striving for.
The actual level of knowledge suggests the following questions and tasks for the next project:

Thermal prospecting as an independent method

Is it possible to detect buried structures, which at an early stage can exclusively be documented as warm crop marks of 1st order?
How long do they already exist before the first volatile classic crop mark appears.
To find an answer to these questions, regular flights starting one month earlier than in the summer-2005 project should to be carried out

Time of flight

The assumptions to the best time of day for prospecting should be checked.
For this purpose at good visibility a diurnal flight over the object should be carried out in intervals of one hour.

Camera

How high is the maximum precision of detail in the thermal image?
The rather modest resolution of the camera (140x140 pixels) used up till now does not allow a statement concerning the actual existing thermal information on the canopy.
A more modern camera with a higher resolution should be used in the next campaign.

Warm positive crop marks

I. Scollar classified classic positive crop marks in the early ripening phase as cold crop marks in the thermal image.
These should also show up as „cooler“ crop marks when water shortage is present in the riper phase of growth, because compared with the surrounding canopy they do not react to the water shortage.
To show this, specific prospecting flights should be carried out over known ditches and embankments.

Kaiserslautern, 2005-12-21
Ulrich Kiesow
archaeoflug

literature

[1]Scollar, I., Tabbagh, A., Hesse, A., Herzog, I. 1990, Archaeological Prospecting and Remote Sensing, Cambridge ISBN 0 521 32050 X chapter 10