AERIAL THERMOGRAPHY
—A REMOTE SENSING TECHNIQUE APPLIED
TO DETECTION OF BURIED
ARCHAEOLOGICAL REMAINS AT A SITE
IN DALECARLIA, SWEDEN

BY
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ABSTRACT. In preparation for an archaeological excavation at a
road construction site, the top-soil was removed from a strip
approximately 20 m wide. Before the excavation, the area was
thermally imaged from helicopter one August night. Variations
in temperature seen in the thermal images could be linked to
archaeological remains that were later found. The reason for this
is, that buried house foundations etc. have a positive influence
on the ground’s capacity to store energy, which results in a higher
temperature at the surface of the ground above these objects.

Introduction

Since 1976 research about the possibilities of using
airborne thermography for studies of ground pa-
rameters has been done at the Remote Sensing
Laboratory, Department of Physical Geography,
University of Stockholm.

The electromagnetic radiation that is registered
by thermography lies within the wavelength re-
region 3–15 μm. For the temperatures found in our
normal surrounding the maximum radiation effect
lies at 10 μm. This radiation, which is not visible,
can be registered by special instruments. The in-
teresting point with this registration is that the
radiation effect is closely correlated with the
temperature of the radiating object. Thus, in the
natural environment, thermal images mainly ex-
press the temperature variations of the surface of
the ground.

The radiation temperature in the very top layer
of the ground is registered by thermography. The
conditions deeper in the ground can influence the
surface temperature in areas lacking vegetation,
because of the heat conduction capacity of the
material. If the ground is covered by vegetation,
the temperature of the upper surface of the vegetation is registered. This temperature is large-
ly dependent on air temperature, solar radiation
and plant physiological parameters. Vegetation
therefore usually makes the possibility of thermo-
graphy interpretation more difficult, when studies
of the ground are concerned. There are possibili-
ties for obtaining information about the substrate
by studying the temperature of the vegetation.
The dependence of plants on water for transpira-
tion and temperature regulation can lead to the
variations in the water content of the ground being
reflected in the temperature variations, which can
be registered by remote sensing techniques (Lun-

This study concerns vegetation-free surfaces
with more likelihood for a connection between
ground-related factors and heat radiation. The
ground absorbs energy, mainly radiant energy
from the sun and atmosphere, which is trans-
formed to heat. The heat energy radiates back in a
way that is determined by the thermal qualities of
the ground. Thus, the supply and storage of en-
ergy result in a surface temperature, which deter-
mines the strength of the radiation energy emit-
ted. For the undisturbed soil profile, water con-
tent is the most significant factor in the thermal
behaviour of the ground (Chudnovskii 1962). The
thermal inertia of the ground, or in other words
how quickly the ground adjusts to temperature
changes in the air, is determined mainly by the
water content. Several investigations have estab-
lished the possibility of using this relationship for
the mapping of soil water by airborne thermogra-
phy (Idso et al. 1979).

The possibility of using airborne thermography
to discover archaeological remains concealed in
the ground is based on the same theoretical back-
ground. A suppliance of energy, which due to
differences in the soil profile can be stored for
different amounts of time, results in temperature
differences at the surface of the ground. House foundations, for example, can cause such anomalies, but even vestiges of cultivation, land fills and other less obvious disturbances in the soil profile should, at the proper occasion for registration, be detected with the help of thermography. Night time is normally considered as the best time for registration. At night the ground surface temperature is more directly dependent on the thermal characteristics of the ground. This is especially valid for calm, clear nights. The purpose here with the registration is to find objects that influence the ground's capacity to store energy, and one requirement is then the night time cooling. The thermal images presented in this article were registered at midnight, at the end of August, 1983. The registration night was calm and the sky was clear. The day before, like the whole summer, was characterized by dry, warm weather.

Mapping of archaeological remains with thermography

In connection with the construction of a new main road outside of Leksand, Dalecarlia, Central Sweden, several localities traditionally known for medieval and older settlements were affected. In preparation for obligatory archaeological excavation within the area to be covered by the projected highway, the top-soil was removed from a strip approximately 20 m wide. Before excavation was begun, the area was photographed and thermally imaged from helicopter during a day and night in August. An example from the aerial photography is reproduced in fig. 1.

The aerial thermography was carried out just before midnight, using a so called Infrared Imaging Radiometer. The radiometer has an instantaneous field of view of 4 mrad, which covers an area about 0.8×0.8 m, from 200 m above ground. The instrument, which functions at the wavelength region 8–12 μm, has, according to the specifications, potential for detection of temperature differences as small as 0.1°C. The information registered is recorded on a video cassette, so that it can later be presented on a monitor and make study and analysis possible. Examples of thermal images photographed from the screen are presented in fig. 2. In addition to the thermal images, a map over the same area is presented in fig. 2, with the archaeological remains found during excavation marked.

In the thermal images the area stripped of top-soil is seen mainly as a dark band edged by lighter
Fig. 2. Night-time thermal images and a map over parts of the vegetation-free surface shown in figure 1. In the thermal images the grey-tones are correlated to the temperature of the ground, lighter tones for warmer areas. The map shows the archaeological remains, hidden in the ground at the time for the aerial thermography. There is a connection between these remains and warm areas in the thermal images.
Fig. 3. Night-time thermal image over an agricultural district in Uppland, Sweden. The image covers an area about 1 x 1.4 km². Light areas are warmer than dark areas. The coldest surfaces are fields with crops. Remaining areas are vegetation-free fields, where the radiation temperatures (grey-tones) were well correlated with the soil moisture content. Some details are marked in the image: 1. Sandy parts, dry and therefore cold, in the clayey fields. 2. Water, warm, in a ditch. 3. Small fires. 4. Small vegetation-covered, cold areas. 5. Crops, cold. 6. Roads, cold (Lundén 1977).
surfaces, which means that surfaces lacking vegetation have a lower temperature compared with the surrounding fields. The small dark surface in the center of each thermal image is an aluminium plate that is used for orientation. Aluminium is a material with extremely low emissivity—poor ability to emit—a fact that has been exploited in this study. Aluminium plates, 0.5 × 1.0 m large and 0.15 mm thick have been set out at fixed places within the area studied. Because of their low emissivity, the plates functioned as reflectors of the cold sky radiation, and they therefore look like cold spots in their surroundings. There are lighter—warmer—parts in the stripped area. Comparison with the map, fig. 2, shows that these anomalies correspond well with the archaeological remains found later during excavation. Thus, the archaeological remains had a positive effect on the surface temperature of the ground that August night. The reason for this must be a better capacity to accumulate the incoming energy—a higher thermal inertia in the “disturbed” soil profile as compared to the “natural” one. An increase in the thermal inertia can be caused by the occurrence of rocks in buried house foundations or by the compaction of the soil.

It should be emphasized here that this study concerns a surface from which the top-soil has been removed. The occurrence of a layer of loose top-soil results in the insulation of the underlying ground, which influences negatively the relationship between surface temperature and the appearance of the soil profile. At present there is no precise answer about the extent to which this influences the potential of the technique. According to a French study (Tabbagh 1984) one way to minimize the effect from a heterogeneous surface layer is to register in clear weather during the early morning. Additional theoretical studies and practical experiments are probably needed in order to arrive at the optimum registration time for different situations.

The potential for mapping is therefore based on the direct effect that the archaeological remains have on the ground’s capacity to store energy. A more indirect theory exists as the basis for thermal mapping of this type. Buried house foundations, etc., influence the drainage capacity of the ground. As has been mentioned, water content is the most significant ground-related factor for the thermal behaviour of the ground, so differences in infiltration in the ground should produce temperature differences at the surface of the ground at certain times. A suitable time for registration is spring, when the surface of the ground is drying out following the melting of the snow, and when the fields are largely free from crops. A thermal image registered one April night is shown in figure 3, and it distinctly depicts the temperature pattern caused by variations in water content in the vegetation-free areas of the fields. The quite obvious effect that the sandy areas (indicated by 1 in the thermal image) have because of their more rapid desiccation and consequently rapid night-time cooling when compared to the surrounding areas of clay, should be comparable to the influence that buried house foundations, for example, would have. Moreover, the ground is warming up in the spring and the higher thermal inertia in a stony soil profile should thus reinforce the temperature anomalies caused by a more rapid desiccation.

Conclusions
There is a good possibility of detecting archaeological remains buried in the ground using aerial thermography. A study in which archaeological remains in the soil profile caused anomalies that could be registered by thermography was presented in this article. Buried house foundations, etc., having a positive effect on the ground’s capacity to store energy, resulted in a higher temperature at the surface of the ground, a fact observable on thermal images registered from helicopter one night in August.

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