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# REMOTE SENSING WITH A THERMAL IMAGER ON AN ENVIRONMENTAL HELICOPTER

## FIRST EXPERIMENTAL RESULTS

BY

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**Abstract**

In 1992 several test flights with a colour coded thermal imaging camera on a BK 117 were made at Eurocopter Germany. The task was to get first experience of apparent IR-signature of a landscape in top-view from a helicopter (HC). The measurements were made on a research farm with the intention to find a relation between surface temperature and soil moisture. During measurements on a waste deposit a hot spot was found. At present experiments are performed with an additional scanner in the 3-5 µm range mounted parallel to the line of sight (LOS) of the initial scanner with a 8-12 µm detector. Actually an environmental helicopter is in development, which will be equipped with several sensors including a spectroradiometer for the visible and near IR wavelength-bands.

## 1. Introduction

Airborne HC remote sensing systems have proved to be very useful for monitoring agriculture and coastal regions, for rapid assessment in response to environmental pollution and disasters and for demonstration of new sensor concepts; see chapter 2 and ref. 1-9.
A BK117-helicopter was equipped with a real-time, colour-coded thermal imaging camera from AGEMA which was used in an experimental trial to monitor AGRO-ECOsystem FAM (Forschungsverbund Agrarökosysteme München) and a waste deposit. The Thermovision 900 camera is a temperature measurement system with a spectral response in the ranges of 3-5 µm and 8-12 µm. The resolution is 12-bit for high image quality to get IR-signature from a.m. agro-ECO applications. The measured data were digitally stored for each image and live scenes were recorded on video tape. During summer 1992 EUROCOPTER Deutschland (ECD) has made several flight campaigns. One campaign was extended with three flights during a day to learn about the temperature/radiance changes; see chapter 3 and 4.

With the remote sensing of rural surfaces it is possible to measure surface temperatures not only of single points on ground (grid of 50 m x 50 m). These surface temperatures depend mainly on the content of moisture of the soil. Effects of solar radiation, wind, plant parameters incl. spectral emissivity/reflectivity and the angle of detection have to be taken into account during the evaluation/interpretation. The paper represents results of the spectral radiance of different materials, the daily course of radiance and the relation between surface temperature and soil moisture; see chapter 4.

Additional measurements on a waste deposit showed strong chemical activity for some parts of the disposal which could not be seen in the visible spectrum; see chapter 5.
At present there are ongoing experiments with an additional scanner (3-5 µm) mounted parallel to the LOS of the first camera head (8-12 µm). In a ground measuring campaign different kind of trees were analysed; see chapter 6.
The trials will be extended in the future with an helicopter-mounted spectroradiometer (visible and near IR Range) to detect the red-edge effect of chlorophyll. With this remote sensing techniques the crop type, the surface roughness, the growth of vegetation (biomass), evapotranspiration, vitality of plants, vegetation stress etc. can be monitored by thermal imaging systems mounted in helicopters; see chapter 7.

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## 2. Advantages of an Environmental Helicopter

The tasks resulting from the "Earth Environment" are just as versatile as complex and expending. They can only be solved by a co-ordinated action, by integrating modern technologies and by the use of existing institutions. The tasks are the investigation of the actual status of the environment for detecting the global change, a continuing surveillance and an early analysis of environment-relevant parameters of influence. These spectrum of tasks can be fulfilled only partially by stationary measurement facilities.

The helicopter is able to take over an essential part in the diagnosis and all kind of surveillance functions. The helicopter is capable of reaching a maximum number of measuring positions in a minimum of time unaffected by ground structure or obstacles.

- **The mobility of the helicopter (HC) cannot be matched by any other means of transportation.**
- **The HC is able to hover or to fly slowly and to cross distances at high speed.**
- **It can fly through narrow valleys and land on mountains inaccessible on ground.**
- **It can take samples out of the air, the water and from ground.**
- **HCs can complement and detail a concept for environmental monitoring by providing a powerful means for local and regional missions and fill the gap between satellites (global) and ground based stations (local); calibration of EO- or radar-sensors installed into a satellite is possible**

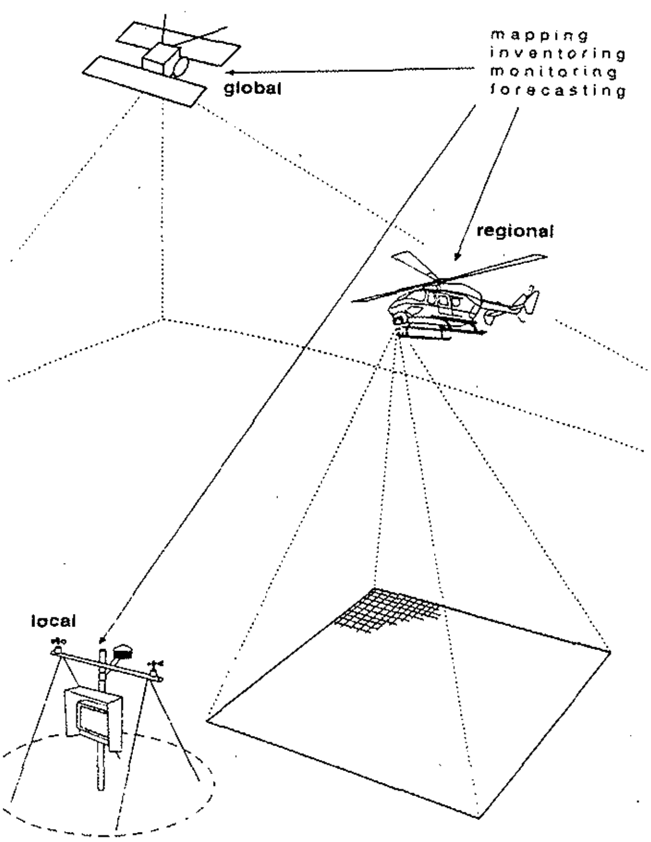


Fig. 2.1: The helicopter (regional) fills the gap between satellites (global) and ground based stations (local).

## 3. Measurement equipment

The measurements described in this paper were made with an infrared (IR) measurement system from AGEMA. For all the flight experiments a BK 117 from ECD as a platform was used. This helicopter with a maximum take-off weight of 3.350 kg is well suitable as sensor platform because of the spacious unobstructed cabin/cargo compartment. The maximum cruising speed at sea level is 133 kts (247 km/h) with full load, the range with maximum standard fuel capacity is 540 km.

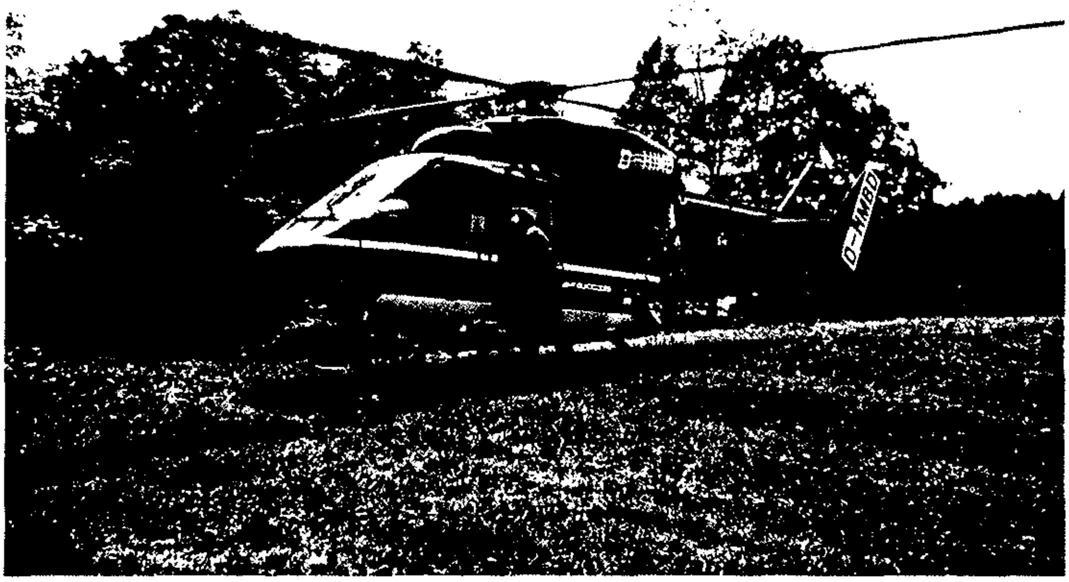

Fig. 3.1: The BK 117 during a landing on the FAM research area.

### 3.1 AGEMA infrared measurement equipment

The AGEMA "Thermovision 900 Series" infrared system is not only an imaging system like a FLIR but a surface temperature measurement system. It consists of two scanners with Stirling cooled detectors, one for the short-wave band (3-5 µm) and one for the long-wave band (8-12 µm), both equipped with lenses providing a 5 x 10 degrees field of view (FOV), a system controller, a special keyboard, mouse and VGA monitor. Both scanners can be used real-time parallel in order to get bi-spectral images.

The pre-processed data from the scanners were send to the system controller and after the main processing digitally (12-bit = 4096 levels) recorded on a 100 MB Winchester disk drive. The system controller software supports advanced image processing and analysis. The operator uses the keyboard and mouse in a familiar, easy-to-use X-Windows environment with pop-up menus. All operation modes of the scanners like the remote focus adjustment can be controlled by the keyboard or by the mouse. The analysis capability includes statistics, emissivity equalisation, atmospheric modelling based on the LOWTRAN model in addition to basic functions like level and range adjustment and provides profiles, areas of interest, histograms and spotmeters. Images can be analysed either in real-time or after retrieval from storage. To ensure maximum accuracy, especially in long-distance measurement, all relevant object and measurement parameters such as emissivity, reflected ambient temperature, object distance, relative humidity and atmospheric temperature are taken into account. The output of the data to personal computers (DOS) or other systems can be done via a 3,5" disk or via Ethernet™. The presentation on a VGA display is standard, but it is also possible to get an on-line composite video signal as output.

Table 3.1: The most important technical data of the two AGEMA IR-scanners

| Typ | **900 LW** | **900 SW** |
|---|---|---|
| Detector type | MCT<br>Stirling cooler | 2xInSb, parallel scanning,<br>Stirling cooler |
| Spectral response | 8 - 12 μm | 3-5 μm (exactly 2 - 5.6 μm) |
| Frame frequency | 15 and 30 Hz, selectable | 15 and 30 Hz, selectable |
| Line frequency | 2.5 kHz | 2.5 kHz |
| Lines/frame | 136 | 136 |
| Spatial resolution at 50% modulation<br>- elements per line<br>- mrad (at 10° FOV) | <br><br>230<br>0.76 | <br><br>200<br>0.87 |
| Samples/line | 272 | 272 |
| Temperature range | -30 to +1500 °C | -20 to 500 °C |
| Sensitivity at 30°C | 0.08 K | 0.1 K |
| Dynamic range | 12 bit (4096 levels) | 12 bit (4096 levels) |
| Weight | 3.5 kg | 3.5 kg |
| Lenses | 5° x 10° | 5° x 10° |

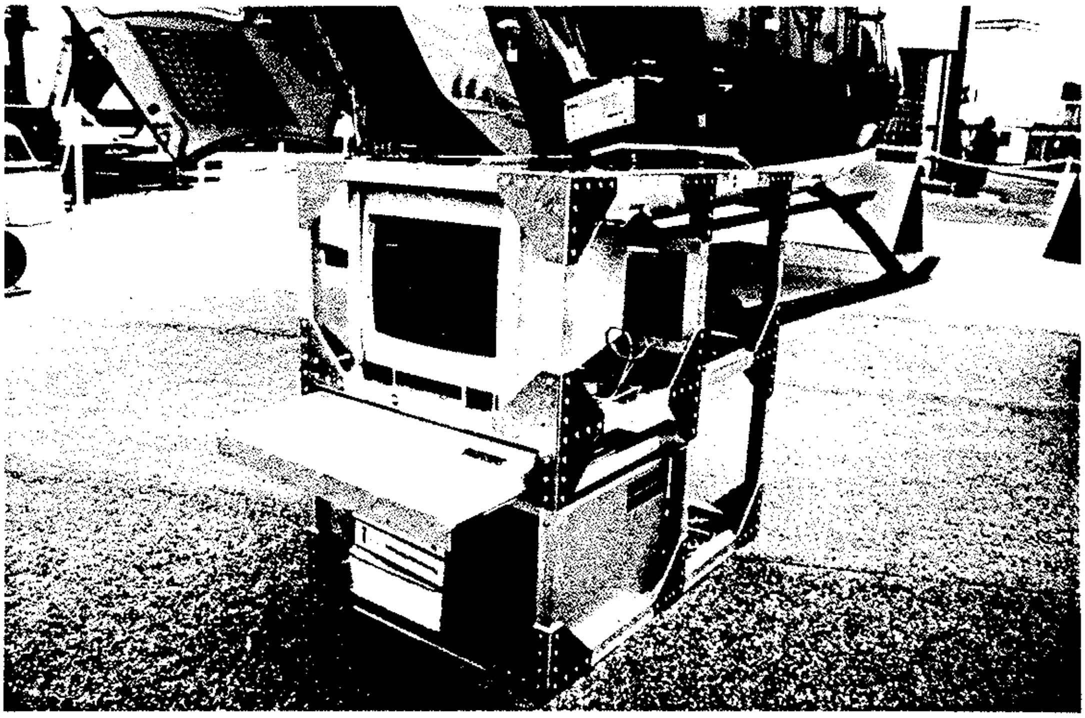

Fig. 3.2: The AGEMA measurement equipment with the 3-5 μm and the 8-12 μm scanner mounted in an Aluminium-Rack is ready for helicopter flight trials

### 3.2 Measurement set-up in the helicopter

The measurement trails described in this paper were made as experimental tests. In the helicopter no fixed provisions were installed for the measurement set-up.

For the measurement flights the whole system was mounted in the helicopter behind the pilot's seat. The scanner was held by a flight-test engineer sitting on the cabin-floor in the open sliding door. In order to get the desired LOS with the IR-scanner, the flight-test engineer had the possibility, to look into the monitor with the IR-image. The video signal of the IR-image generated in the AGEMA system-controller was recorded on a video tape during the whole flight tests. A small CCD black/white camera was mounted on the scanner and adjusted parallel to the scanner's LOS. This black/white signal was recorded additionally on a video tape recorder for better documentation of the IR-images. The vibration attenuation was made with some pieces of foam. No problems appeared by HC generated vibrations. Even operating a standard mouse was possible.

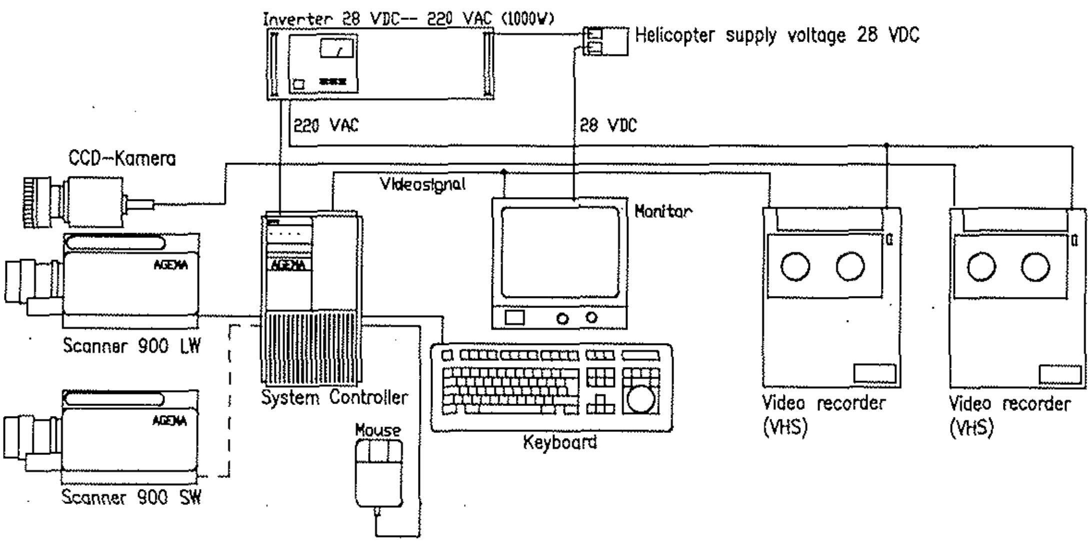


Fig. 3.3: Block diagram of the AGEMA measurement set-up

## 4. AGRO-ECOsystem FAM-Project and results

### 4.1 The FAM project

The FAM (Forschungsverbund Agrarökosysteme München) project is a long-term research experimental program initiated and performed by a number of institutes of the Technical University of Munich and the GSF (Forschungszentrum für Umwelt und Gesundheit GmbH near Munich). The main purpose of the research network FAM is to evaluate changes in land usage of cultivation in agro-ecosystems.

At the research farm (143 ha) "Klostergut Scheyern" (FAM project) in the tertiary hills near Munich three types of cultivation are situated - conventional agriculture, sustainable agriculture and landscape conservation. These types will be monitored in their influence on the ecological and economical cycles in the ecosystems especially on ground. Therefore a network of different kind of climatic and soil-ecological sensors was installed and distributed over the experimental area. Data were taken on ground. The measurement data of these in-situ sensors were recorded in the Geographical Information System (GIS) where they can be combined with additional sensing information. This extensive data basis GIS is not only helpful but also indispensable for the validation of remote sensing data.

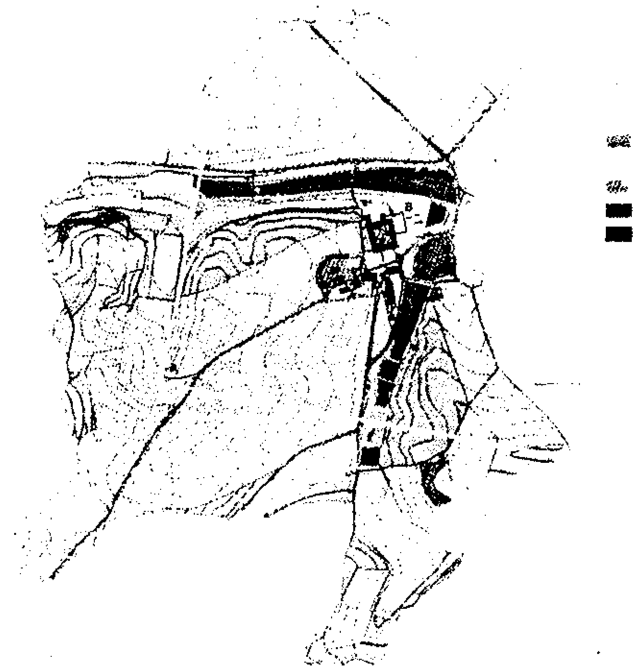

Fig. 4.1: Map of FAM research area Scheyern

**4.2 Measurement flights and interpretation of results**

In 1992 four measurement flights with the AGEMA colour-coded thermal imager were performed. The intention of these flights was, to get first experience in the IR-signature of a landscape and to learn about the problems arising from physical constraints as well as from technical aspects.

The first measurement flight was on the 26th of May between 13:00 and 14:10 h. There were no clouds and the ambient temperature was about 25°. No precipitation's occurred in the week before and so the soil was relatively dry. In addition there was a weak and dry wind from East. These conditions caused high contrast in the detected surface temperatures.

The second flight campaign consisted of three flights distributed over one day, the 13th of July. The first flight of this day was in the morning from 10:30 - 12:10 h, the second one in the afternoon from 14:00 - 15:30 and the third one in the evening from 17:00 - 18.25 h.

The flight campaign started always from ECD site in Ottobrunn near Munich. During the first test flight only IR-images from three special areas of the FAM research farm in Scheyern were made: 1.) a slope inclined to West and about 20 meters high, 2.) a flat area and 3.) a little fish pond. Three flight altitudes were flown: 150, 300 and 600 meters. At the second campaign on 13.07.92 the FAM area was scanned three times (morning, afternoon, evening) by flying 16 stripes side by side in an altitude of 600 meters. For the inclined slope, an altitude profile was taken in addition. This results in a sequence of IR-images taken between a minimum altitude of 100 meters and a maximum altitude of 1000 meters. On the way back from FAM the flight path of each flight was directed over Munich's waste deposit north of the city area. Images of this object were taken there from an altitude of about 150 meters.

Fig. 4.2: Photo of the FAM research area with several fish ponds in Scheyern north of Munich. At the bottom of the image-centre there is the little fish pond "Teufelsweiher" (compare Fig. 4.7).

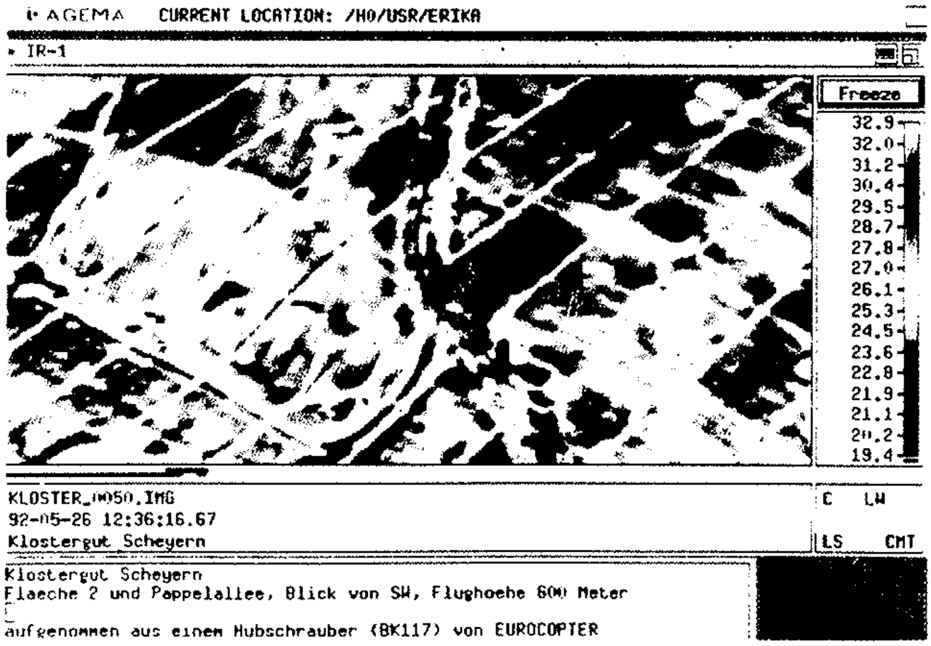


Fig. 4.3: IR-image in the 8-12μm band. From top to bottom of the image centre there leads a little street with trees (dark points are trees). Clearly visible are also the "50 meter stripes" of the FAM-research area, which are necessary for measurement purpose e.g. soil temperature, soil moisture etc. With the IR-remote sensing technique it is possible to detect surface temperatures in two dimensions!

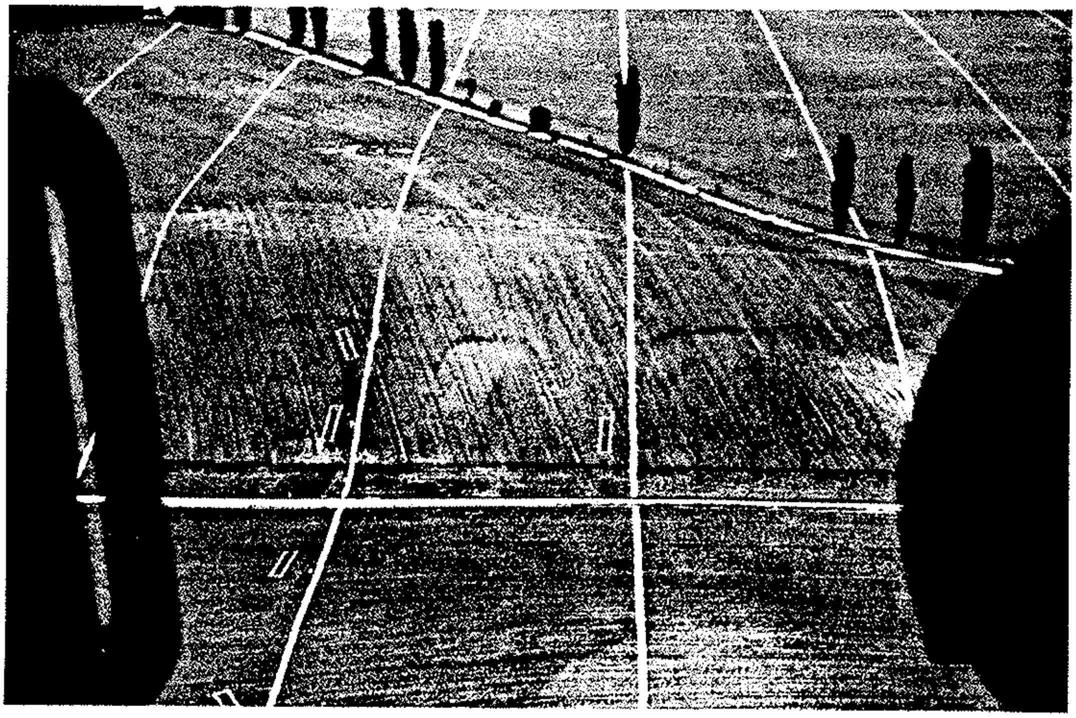

Fig. 4.4a: This photo shows the street with the alley trees and in the centre the slope with the "50 meter stripes", which are used for single point measurements on ground with a grid of 50 m x 50 m

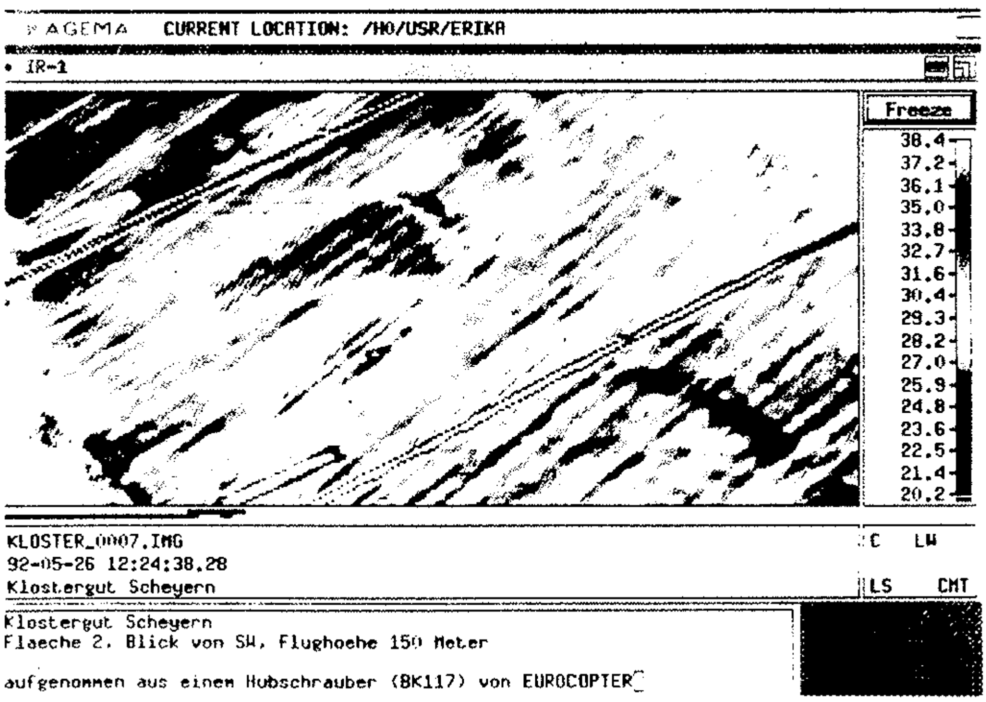


Fig. 4.4b: This detailed IR-image shows a part of the slope, compare Fig. 4.4a; here two noticeable areas are visible, one in red and one in blue. Remark: only detectable in a colour-coded print out.

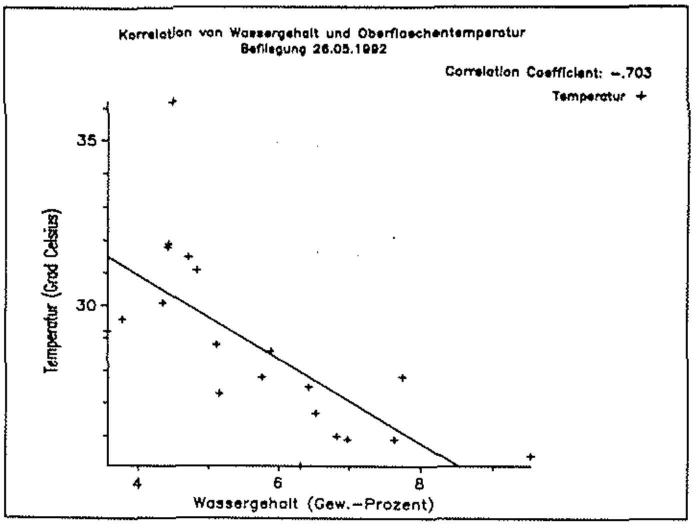


Fig. 4.5: Surface temperature versus soil moisture (water content) at FAM taken on ground by ecologists dd. 26.05.92. Each cross is a sample point.

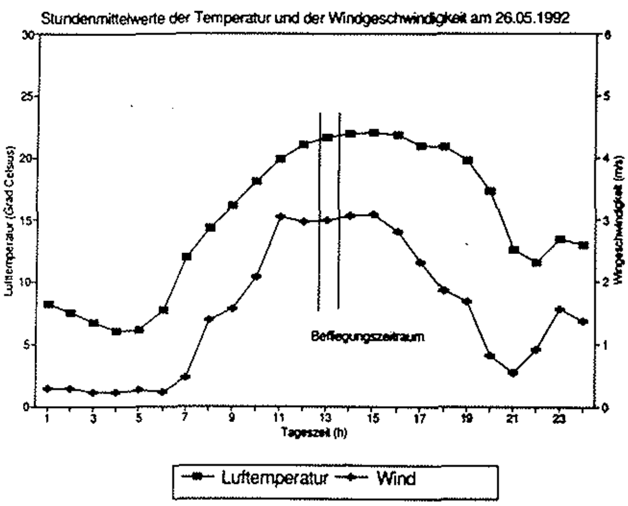


Fig. 4.6: Mean values of air temperature (□, co-ordinate on the left side) and wind speed (+, co-ordinate on the right side) as a function by daily course at FAM dd. 26.05.1992.

The trees in Fig. 4.3 are dark (cold, 19.5°C), which indicates cooling by evaporation, or/and cooling by wind effects or high reflectivity of sun radiation.

In Fig. 4.4b the dark blue (cold) areas indicates a lens of clay which stops water flow in the slope. The red (hot) area beneath, compare again Fig. 4.4b, shows dry soil. These effects were investigated by soil ecologists after the IR-images were taken.

With the IR-remote sensing technique of rural surfaces it is possible to measure surface temperatures not only of single points on ground (grid of 50 m x 50 m). These surface temperatures depend mainly on the content of moisture of the soil, compare Fig. 4.5. Effects of solar radiation, wind, plant parameters incl. spectral emissivity/reflectivity and the angle of detection have to be taken into account during the evaluation/interpretation.

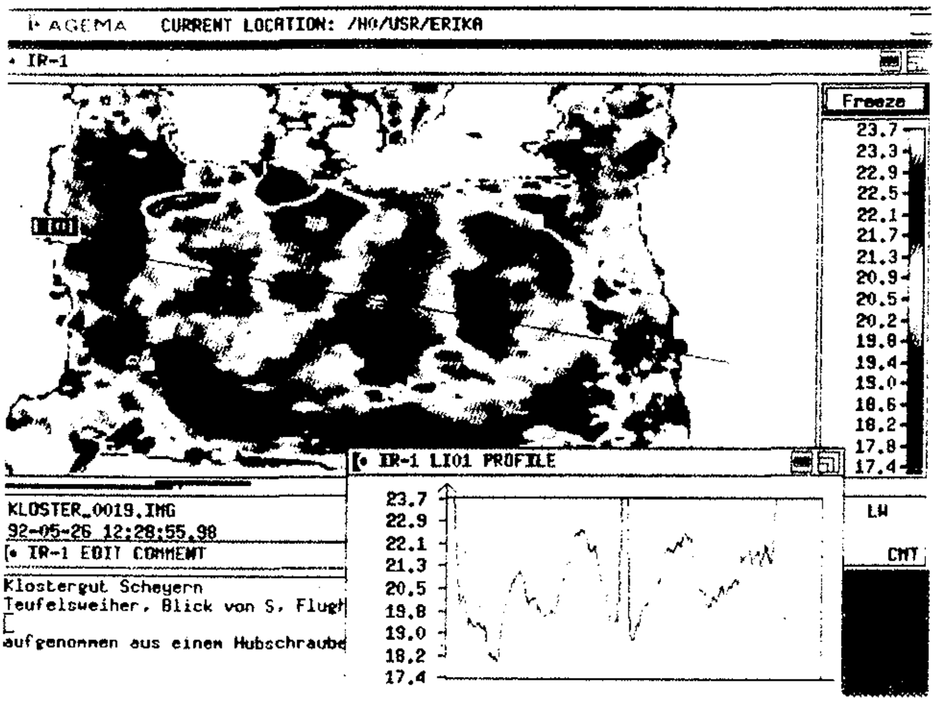


Fig. 4.7: Water surface-temperature in a little fish pond "Teufelsweiher" dd. 26.05.92. At bottom of the picture a profile of surface temperature across the IR-image. The temperatures vary between 18.2°C and more than 23.7°C

The surface of water, compare Fig. 4.7, can reflect the sky specular in the 10 µm band. But in this IR-image the water surface indicates the emissivity of different contents of sea-weeds. In the middle of the "Teufelsweiher" is a very small island build by metal. The metal temperature > 23.7°C indicates the heating by the sun (solar radiation).

The IR-image sequence in Fig. 4.8a - c shows the daily course at 11:00 a.m., 2:30 p.m. and 6:00 p.m. The three images were not taken from the same HC position! We found out the most suitable areas which show similar surfaces by image processing (geometrical correction) and overlay of the three pictures. The result is presented in Fig. 4.8d. The bright areas are hot and therefore equivalent to dry soil.

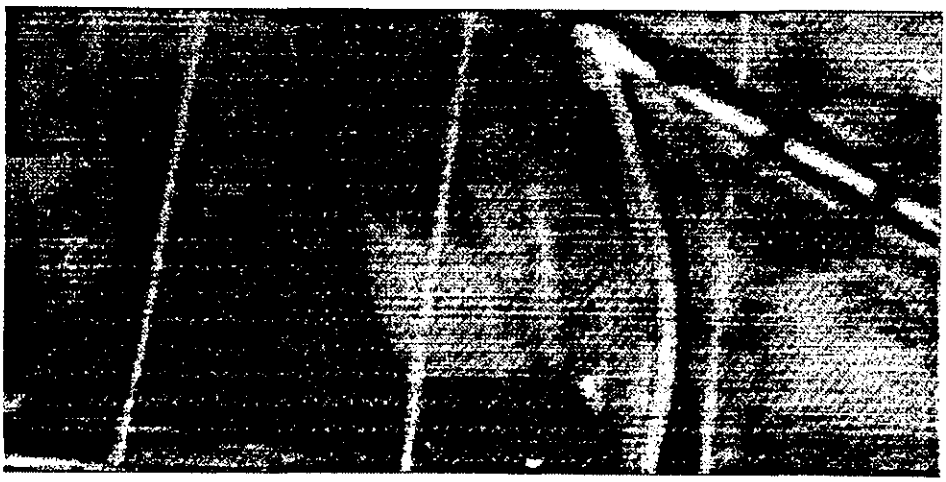

Fig. 4.8a: The slope (see Figs. 4.3 and 4.4) in the morning dd. 13.07.92 at about 11:00 a.m.

Fig. 4.8b: The slope dd. 13.07.92 at about 2:30 p.m. presented with the same temperature level and range as in Fig. 4.8a.

Fig. 4.8c: The slope dd. 13.07.92 at about 6:00 p.m. presented with the same temperature level and range as in Fig. 4.8a.

Fig. 4.8d: Image fusion: Overlay of the three images 4.8a-c morning, afternoon and evening

## 5. Monitor of a waste deposit

### 5.1 Munich's waste deposit Großlappen

Munich's waste deposit consists of three parts: 1. the old deposit hill (South-East), where domestic waste and construction rubble was dumped, and which is now closed and planted, 2. the sewer-mud deposit (North-East) and 3. the new deposit hill for domestic waste and construction rubble (North-East of the motor way intersection). Recently on the new deposit part there was dumped only clinker from the burned domestic waste and building rubble. During the growing up of the deposit, the embankment was covered with earth and planted with low bushes and little trees. The methane gas produced by chemical reactions in the deposit is collected in net of pipes and burned in a vertical nozzle near the deposit hill.

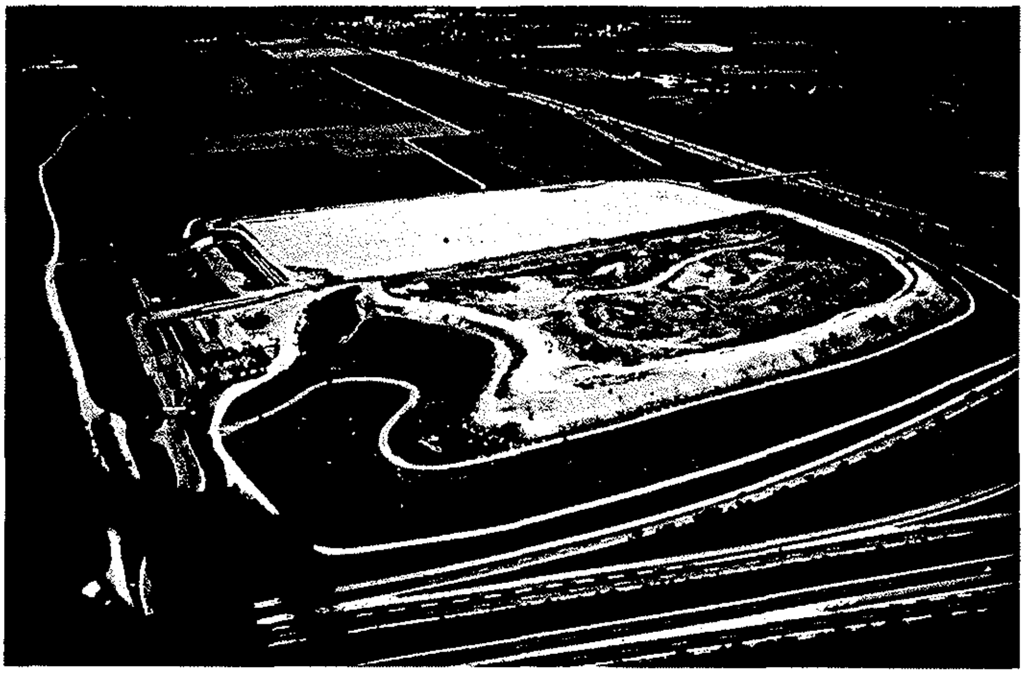

Fig. 5.1: Photo of Munich's new waste deposit North-East of a motor way intersection.

### 5.2 Interpretation of the results

In a waste deposit, especially in a domestic waste deposit, chemical and biological reactions occur. The exothermal reactions cause a heating of the surrounding area up to the soil surface. The so called hot spots can be detected by an infrared temperature measurement system such as the one used in this experiment.

Fig. 5.2 shows the embankment at the South-West part of the deposit. The yellow "S"-shaped band in the upper part of the image is the street leading up the hill. It is good discernible in Fig. 5.1. The most striking part of the image is the red spot at the bottom to the left. The inner dark red area indicates that the sensor is saturated in the actual temperature set-up, which allows temperature measurements in a range from -30° up to 80°C. It is also possible to select other temperature ranges between -30° and +1500°C, but for environmental measurements the applied one is the best choice. A comparison with the video tape and the photos show that the source of this hot emission is the flame over the methane gas nozzle. The flame itself is not visible at daylight.

The embankment shows a surface temperature range from 19°C up to over 42°C. A comparison between the visual image and the IR-image shows, that with increasing plant height the temperature decreases (dark blue). There are two reasons for this fact. First the higher the tree is, the better the wind can reach the treetop and decrease the temperature by evaporation cooling. Second, the denser the plants, the lesser soil is visible and soil will be heated by sun radiation.

The most interesting area in Fig. 5.2 is the hot spot in the centre. The colour code assigns a temperature of more than 42°C to this area. This is an indication for chemical or biological reactions taking place under the surface. Now further investigations of this area should be made by taking soil and air samples and analysing them in the lab. This is a good example to show the advantage of an helicopter in remote sensing of large areas and detecting conspicuous hot spots within a short time.

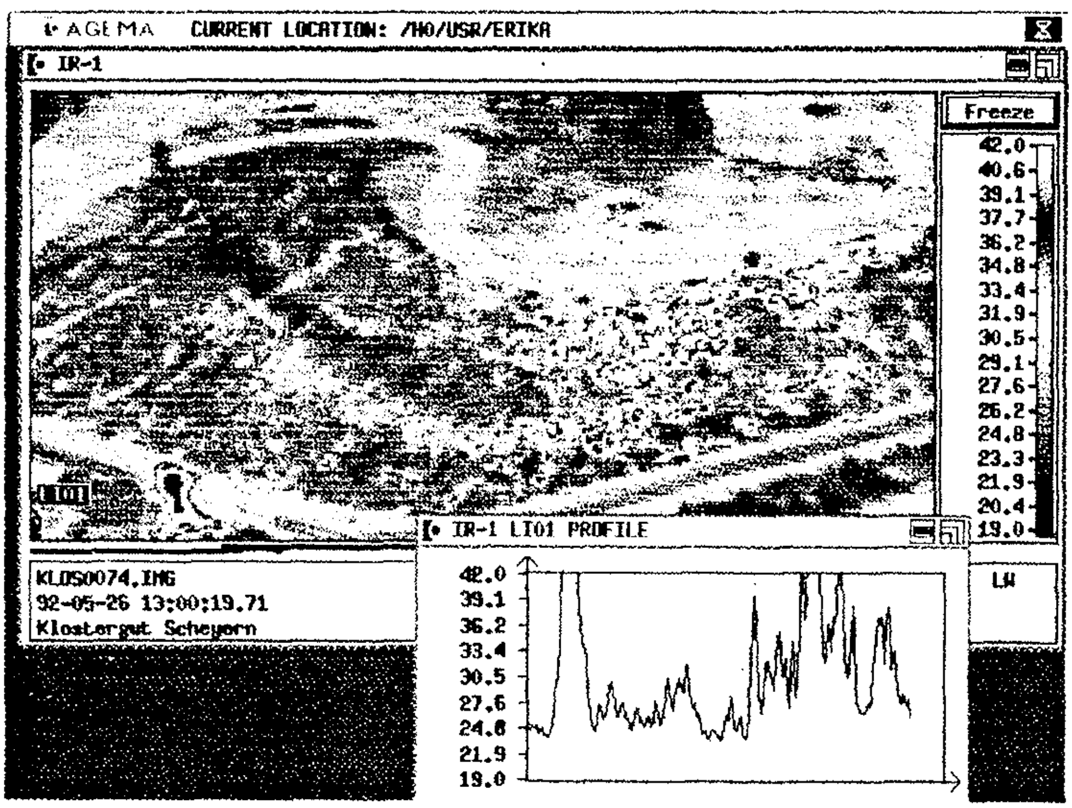


Fig. 5.2: IR-image of a hot spot on a waste deposit, dd. 26.05.92; At the bottom of the picture a profile of surface temperature lead through the IR-image from the lower left to the upper right. The temperatures vary between 19°C and more than 42.0°C. The hot spot in the centre is an indication for chemical or biological reactions taking place under the surface.

## 6. Comparison of measurements in the 3-5 µm and 8-12 µm bands and IR-signatures

### 6.1 Spruce trees

Since several months EUROCOPTER Deutschland (ECD) is equipped with an additional scanner for the 3-5 µm wavelength band (short wave scanner). This scanner can be plugged into the same system controller as the 8-12 µm scanner (see Fig. 3.3). Both scanners can be used simultaneously. So it is possible to record two images of the same object, one in the short-wave band, the other in the long-wave band at the same time by pressing one trigger key. Under the precondition, that the two scanners are adjusted to the same LOS, it is possible to get a real bi-spectral view from objects or landscape. The comparison of the 3-5 µm images with the 8-12 µm images is very interesting. Big differences were found on images of hot gases. These gases show much more IR-signature in the 3-5 µm channel than in the other band. Presently there are ongoing experiments at ECD to investigate the spectral difference of the IR-emissivity of plants/trees. Therefore some measurements on deciduous trees and conifers were made. Figs. 6.1 - 6.3 show some of the results.

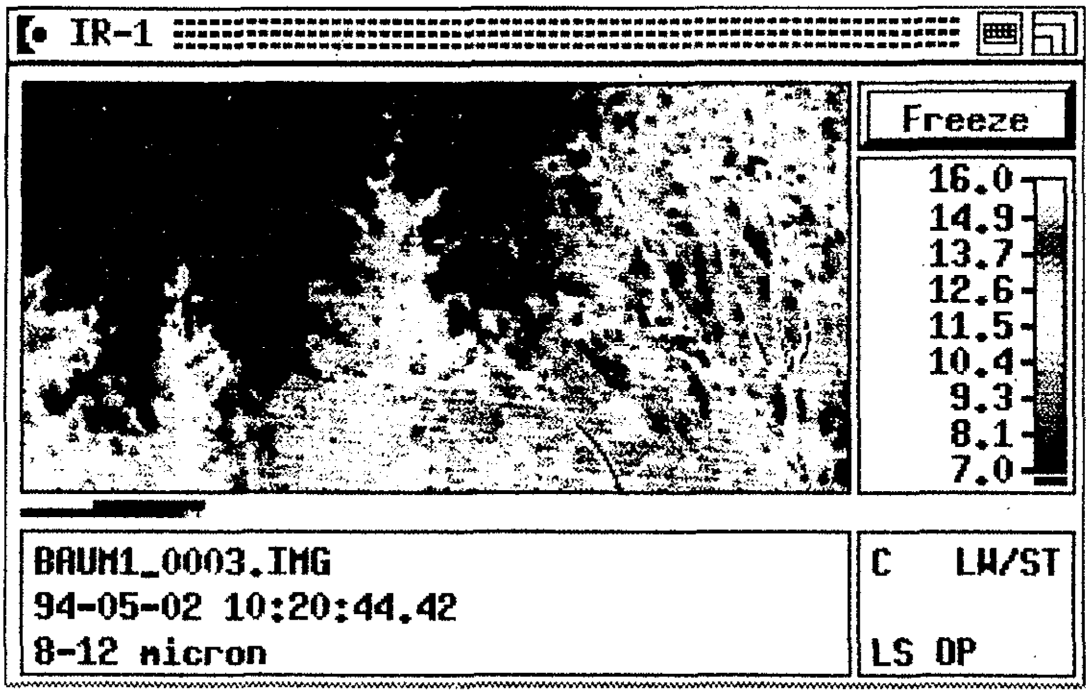


Fig. 6.1: Group of trees, in the centre a spruce and left and right deciduous trees; the IR-image was taken in the 8-12µm-band. March 1994; the temperature range varies between 7°C and 16°C.

In the centre of these images there is a spruce and to the left and the right side are deciduous trees and bushes. The measurements were made in spring of 1994, when all leafs were fresh and green. A comparison of the Figs. 6.1 and 6.2 shows a noticeable difference particularly in the tree tops of deciduous trees. The differences of the spruce's IR-signatures are smaller. Fig. 6.3 presents a difference image between Figs. 6.1 and 6.2. The yellow areas indicate great temperature differences and the dark red parts almost no difference. It is noticeable, that the bark of the tree shows the smallest difference and green leafs of deciduous trees the largest. This image was processed by colour fusion. The detailed interpretation of the results in Fig. 6.3 is a task of foresters.

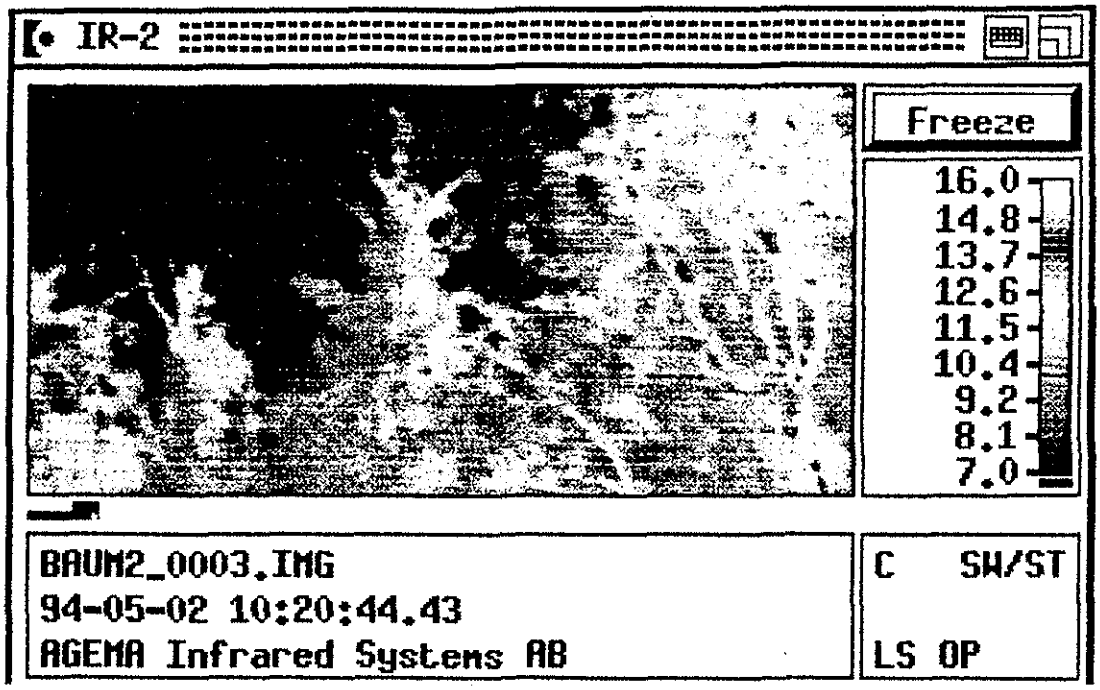


Fig. 6.2: The same IR-image as in Fig. 6.1 taken in the 3-5 μm-band. March 1994; the temperature range varies between 7°C and 16°C

Fig. 6.3: Image-fusion: IR-difference image between Fig 6.1 and Fig. 6.2. Yellow parts indicate a great difference in radiation/temperature. Remark: only detectable in a colour-coded print out.

### 6.2 IR-signature

The pictures in chapter 6.1 show, that the IR-signature depends on the wavelength and the material, because each material has an other emissivity. This fact is also expressed by Fig. 6.4, which shows the spectral emissivity of different materials at wavelengths between 1 μm and 15 μm. A blackbody has the emissivity of 1, per definition and behaves according to the Planck radiation law. Above 3 µm or 5 µm wood, black and white paint, fire-clay and chlorophyll (green leaves) have an emissivity of nearly 1. At the red edge (approx. 700 nm) the emissivity of chlorophyll increases drastically. The edge of the slope is always different for healthy trees and diseased trees. In the 10 µm - spectrum metal has a high reflectivity and a low emissivity.

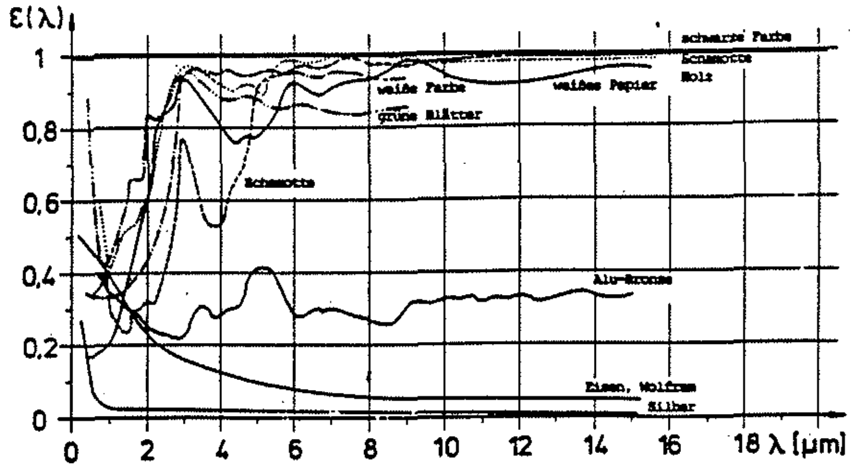


Fig. 6.4: Spectral emissivity of different materials in the 0.5 µm - 15 µm - spectrum

**7. Future HC-projects for Environmental Monitoring and Disaster Operations**

ECD plans to equip Environmental Helicopters with a modular mission/sensor package, see Fig. 7.1. GPS and flight management-system, central data management, telemetry, climatic

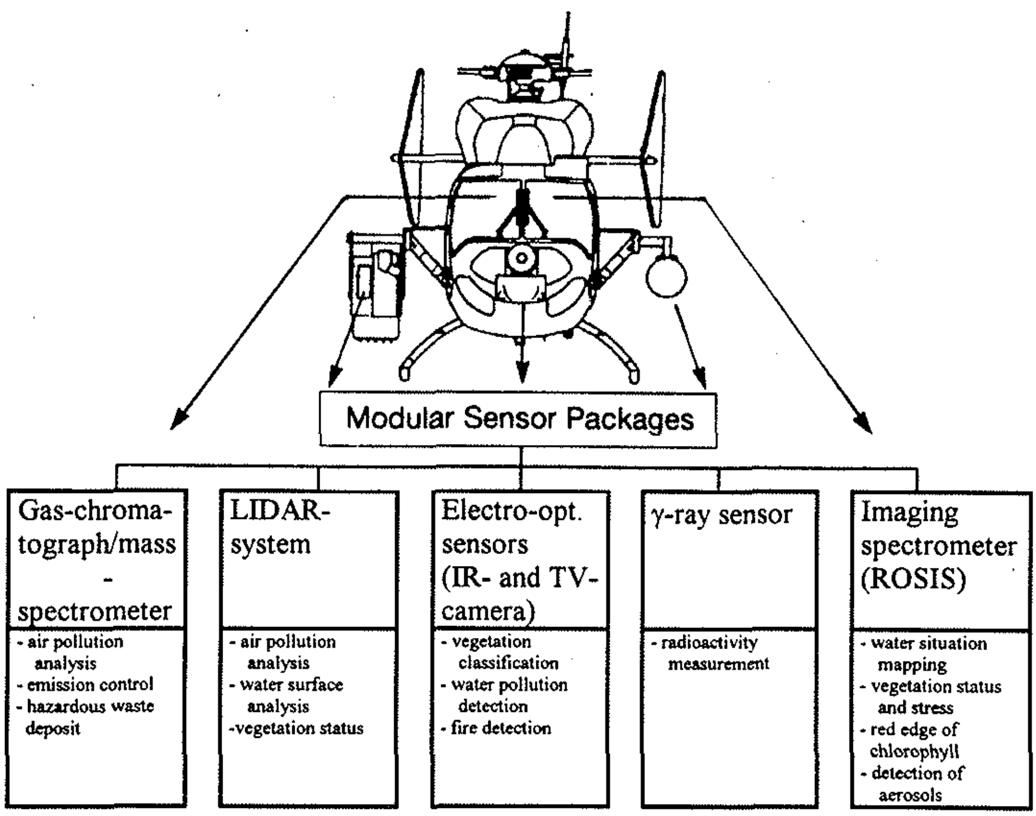


Fig. 7.1: Modular sensor packages for the Environmental Helicopter (UVT).

situation sensors and an operators seat incl. a console are basic equipment's of an Environmental Helicopter.

The sensor tasks are spread mainly into two domains: **remote sensing** and **in-situ measurements of gases**.
LIDAR-systems, Radar sensors incl. a SAR, electro-optical sensors, γ-ray sensors and image spectrometers belong to the active and passive remote sensing devices while a gas-chromatograph/mass spectrometer is suitable for in-situ measurements. For these in-situ measurements the helicopter requires a Pitot tube to avoid false readings caused by turbine gas exhaust in the HC down wash. The calibration of the sensors is a special task for all applications.

With the imaging spectrometer e.g. ROSIS the red edge of chlorophyll (trees, plants) can be detected in supplement to the 3-5 μm and 8-12 μm channels. Sensor fusion can process the vitality of trees/plants and vegetation stress with this tree monitoring sensors. A day-TV-camera will be used always for quick-look aspects.

## 8. Conclusion

The main results of the experiments in the FAM-project are summarised in Figs. 4.4b and 4.5, which shows almost a linear dependency/relation between the surface temperature measured in the 8 - 12 μm band and the soil moisture. Fig. 4.8d combines the daily course of thermal radiance by image fusion. Measurements on a waste deposit showed strong chemical reactions in some parts of the deposit which could not be seen in the visible spectrum, see Fig. 5.2. In the section 6.1 ground measurements of spruce trees indicate the thermal radiation difference in the 3-5 μm and 8-12 μm channel, see Figs. 6.3. Fig. 6.4 shows the spectral emissivity of different materials.

ECD plans to equip a BK117-HC with modular sensor packages for environmental applications.

HCs (regional) can support a system for environmental monitoring by providing a useful means for local and regional missions and fill the gap between satellites (global) and ground based stations (local). The IR-remote sensing technique is suitable for monitoring environmental effects. Additionally this technique can be used to calibrate IR-sensors which are installed into satellites.

## 9. References


(1) W.Kühbauch, "Fernerkundung in der Landwirtschaft", Luft- und Raumfahrt 4/90, page 37

(2) S.Paloscia, P.Pampaloni, L.Chiarantini, P.Coppo, S.Gagliani, G.Luzi, "Multifrequency Microwave Radiometric Measurement of Soil Moisture", IGARSS 1990, Washington, D.C. , USA, May 20-24, 1990, Vol.III p.1837

(3) A.P.Wolframm, C.Bösswetter, B.Kunkel, U.Kraft, H.-D.V.Böhm, D.J.Smith, R.Reuter : "EUROMAR-SEASTARS, a modular Multi-Sensor System for Airborne Remote Sensing of the Sea", IGARSS'91 Remote Sensing: Global Monitoring for Earth Management, Helsinki UNI of Technology Espo, Finland June 3-6, 1991

(4) A.Bianchi, A.Gallotti, C.Koecher, J.Verdebout, "Time resolved LIDAR Fluorosensor operating from Helicopter" presented at the Seventeenth European Rotorcraft Forum, Berlin, FRG, Sept. 24 -26, 1991, page 147, Proceedings of DGLR

(5) G.A.Blackburn, E.J.Milton, "Scale dependence in the reflectance of deciduous woodland: Evidence from a Helicopter-mounted spectroradiometer" Poster presented at: European "International Space Year" ISY-Conference 1992, Space in the Service of the Changing Earth, Munich, Germany, 30.3.-4.4.1992

(6) W.Scheurer, S.Haisch, R.Hanschel, H.-D.V.Böhm, "The Use of an Environmental Helicopter for the Monitoring of AGRO-Ecosystems", Poster presented at: European "International Space Year" ISY-Conference 1992, Space in the Service of the Changing Earth, Munich, Germany, 30.3.-4.4.1992

(7) S.Haisch, H.Schreyer, J.Frank, H.-D.V.Böhm, "Neue IR-Signatur (8-12µm) Meßtechnologie für den Umweltschutz vom Hubschrauber (BK117, Remote-Sensing); Fallbeispiel: Klostergut Scheyern (FAM) und Mülldeponie Großlappen (München), 11.6.1992, ECD-TN-DE412-6/92

(8) H.-D.V.Böhm, P.Behrmann et al. "Studie - Systemansatz Monitoring 2000 - Umweltmonitoring", Band III/Anhang B, Sensortechnologien, Deutsche Aerospace (DASA) 4/1992, approx. 300 pages

(9) ECD Publications: "Helicopters for Environmental Monitoring and Disaster Operations", May 1992 and May 1994