Image processing of HCMM-satellite thermal images for superposition with other satellite imagery and topographic and thematic maps

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1. Objectives

Under the leadership of the Joint Research Centre of the European Communities in Ispra (Northern Italy) a consortium of several European investigators conducts studies of soil moisture and heat budget evaluation of HCMM-data in selected European zones of agricultural and environmental interest (TELLUS-Project).

Some special interests of the Geographical Institute I of the University of Freiburg (GEOIF) in the frame of TELLUS-Project are [2] :

- Connection between the patterns of surface temperatures resp. day/night temperature differences and the geographic reality of various natural surfaces with a different physical constitution (forests, farmland, settling areas etc.) by comparison with already available special maps mainly in the scale 1 : 1 000 000.

- Correlation between surface temperatures resp. their variations and the nature of surface coverage.

- Analysis of the influence of altitude, topographic situation and regional meteorologic conditions on the temperature of surface elements of the same kind.

- Thermal behaviour of different regional units in Southern Germany.

In this paper two questions, both of primary importance for the application of HCMM-image material with regard to the before mentioned goals, will be examined.

It will be examined, how exact a regionally bounded HCMM-scene can be rectified with respect to a preassigned coordinate system (in this case the Gauss-Krüger System for the official maps of the Federal Republic of Germany). Related to this problem is the question of the scale to which excerpts from HCMM-data can be sensibly enlarged or, conversely, how large natural topographic structures must be in order to be identified accurately in a satellite thermal image. This information is a prerequisite for all evaluations in which HCMM-data are related to terrestrial observations or measurements.

Furthermore, an attempt will be made to superimpose computationally point for point the HCMM-image data with other informations, especially relief and forest and population distribution maps, but also with a land-use map, which has been derived from LANDSAT data. Here it is necessary, on the one hand, to digitize the maps and to rectify them, likewise with respect to the Gauss-Krüger coordinate system, and, on the other hand, to combine the various information levels in a single multi-channel data-structure. The thereby requisite methodological steps and the accompanying difficulties, as well as some evaluations of the resultant data-structures, will be presented below.

For this study a section has been chosen from the southwestern part of Central Europe between the cities of Basel and Frankfurt (Fig. 1). This section comprises the so-called Upper Rhine Valley and the surrounding Highlands.

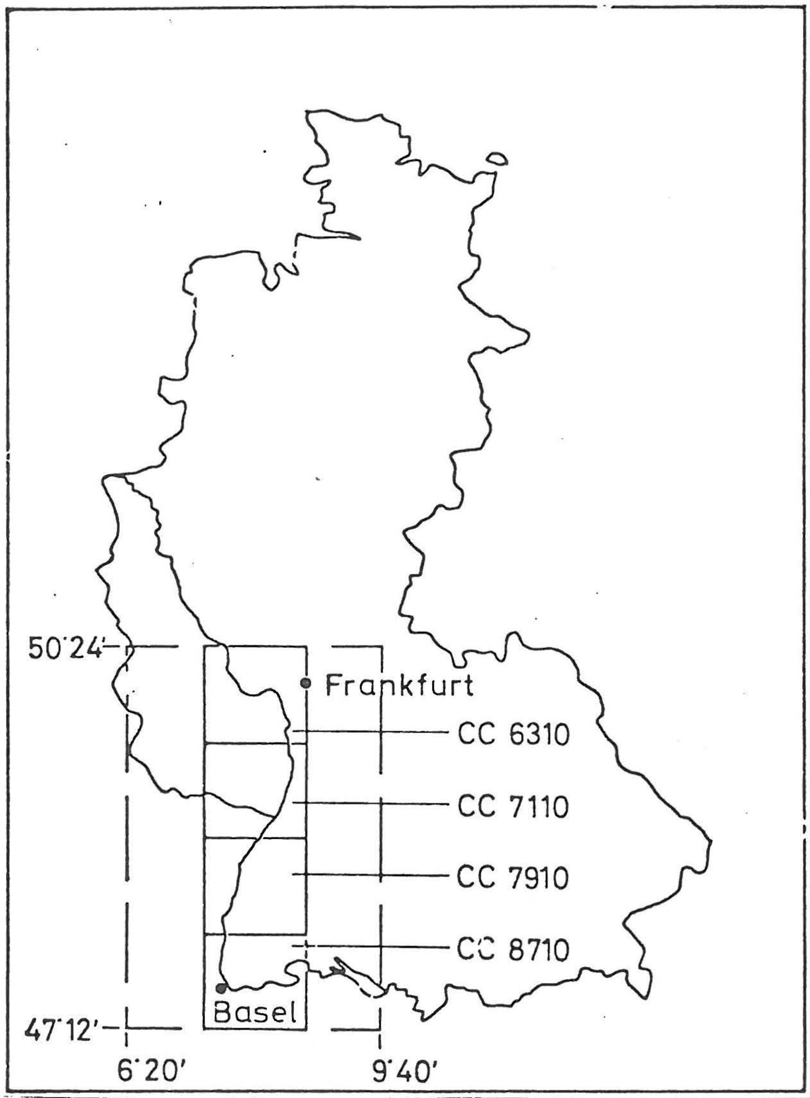


Fig. 1: The area under investigation
CC 6310, CC 7110, CC 7910 and CC 8710 are sheet-numbers of the official Topographical Map 1 : 200 000 of the FRG.

2. Data Base

2.1 Maps

Of all the types of existing thematic maps showing distribution patterns of specific phenomena, two are of special interest with regard to superimposing with satellite images. The first type is the distribution pattern of land-use types, in which the illustrated area is composed of "sub-surfaces", each class of sub-surface representing a particular geographic quality, as is the case with land-use maps. The binary distribution maps of a land-use category (binary mosaic map), such as those for forest distribution or the distribution of tilled or settled acreage in a given area, are special cases of this type. The second map-type is comprised of the iso-line representation of a continuum, i.e., of a continuous field which fills the observed area, as e.g. the contour representation of land forms. On the other hand, maps constructed on the basis of a network of linear elements, such as the network of rivers, streams, lakes, etc., of an area, can only be used for orientation purposes or as a frame of reference, since, because of the extraordinary broadness of the line, the image-elements which appear on the map as bodies of water must not necessarily represent water in the satellite image, too.

One example of each of these two map-types has been selected for investigation. In choosing an appropriate scale the geometric resolution of the satellite thermal-image was the decisive factor. Assuming the smallest possible size of the map-elements to be 0.3 mm x 0.3 mm, the pixel size of 600 m x 600 m corresponds to a scale of 1 : 2.000 000. Therefore, in the digitalization maps of the scale 1 : 1.000 000 and 1 : 2.000 000 have been employed.

2.2 LANDSAT image sources

As above mentioned LANDSAT image data were used as a further data base. These data were produced in connection with an investigation of the application-possiblities of satellite-image data in the regional planning sector. Specifically, the data sources are two LANDSAT scenes of southwestern Germany, the one dated 8/9/1975, the other 8/28/1975, both of which were geometrically rectified and adapted to the Gauss-Krüger coordinate system. Segments of both scenes have been fitted together so as to form a mosaic which covers the map CC 7110 (Mannheim, scale 1:200 000). Each pixel of the rectified and CC 7110-fitted scenes describes a surface of 100 x 100 m2 (1 ha). The following 8 classes were established by multispectral classification: high-density urban built-up, low density urban built-up, water, pastures and orchards, tilled acreage, vineyards, deciduous forest and coniferous forest. The so classified scene is available as a data-structure which can be combined with other data sources.

2.3 The HCMM scene

Although the HCMM satellite had been operating for a year when this investigation was carried out, there was only one image available for evaluation, namely from May 30, 1978, 2:13 GMT (Fig. 3). This was because, firstly, the high degree of cloud coverage over Central Europe renders many images unusable and, secondly, due to scheduling conflicts with other NASA programs, the European ground stations in Madrid and elsewhere could not register data during the clear-weather period of October 1978.

On the other hand it has not been a disadvantage that the studies on combining thermal information with the afore mentioned information have had to be centered up until now on a single image. As soon as they are available, new images can be integrated easily into the data-structures which have already been produced and can be thus subjected to multi-temporal observation.

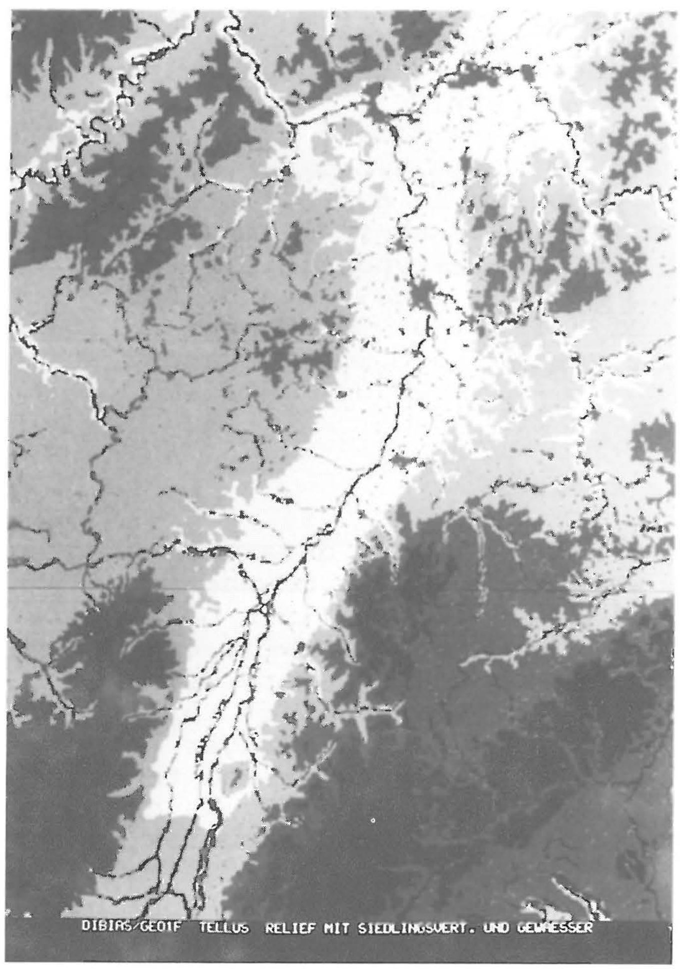


Fig. 2: Result of the digitalization of different maps. Superposition of the relief with the distribution-pattern of urban built-up areas and the river network.

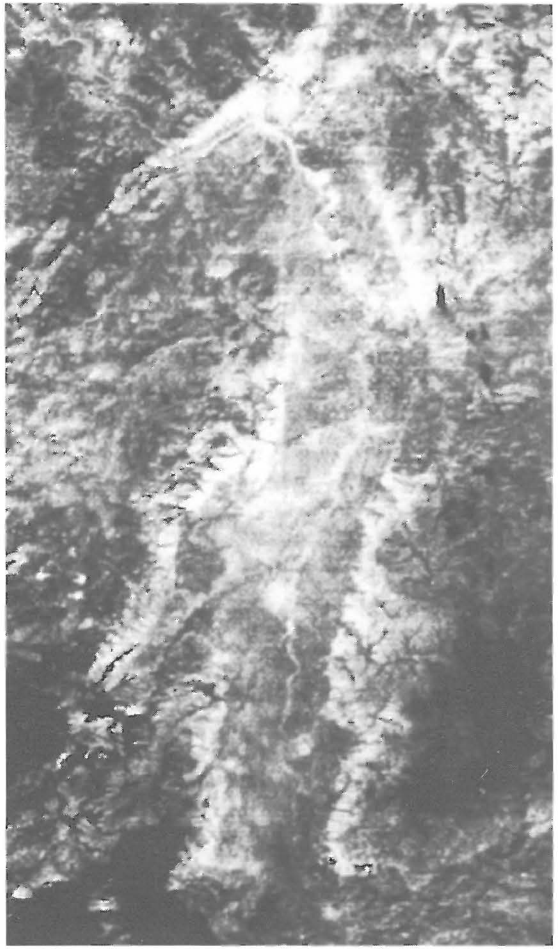


Fig. 3: A section of the thermal infrared HCMM-satellite image (5/30/78, 2:13 GMT). The section shows the Rhine Valley between Basel and Frankfurt and the surrounding highland (bright = warm, dark = cold).

Fig. 4: Forest Distribution in South-West Germany form Hydrologischer Atlas der Bundesrepublik Deutschland.

3. Preparation of auxilary data (map digitalization)

Map digitalization was achieved by scanning 6 x 6 cm^2 slides with a DICOMED-Flying-Spot-Scanner (DIBIAS System). This system allows a resolution of the image in 1024 x 1024 pixels. Considering the extension of the Upper Rhine Valley and its surroundings this result in a pixel size of ca. 350 x 350 m2 (cf. Fig. 2). This resolution corresponds approximately to the accuracy of the map:
350 m $\hat{=}$ 0.35 mm and 0.175 mm in scales of 1:1 000 000 and 1:2 000 000, respectively. At the same time it is somewhat better than the geometric resolution of the thermal-image.

The digitizing of gray levels which appear on the maps presented considerable difficulties. It proved to be impossible to carry out the digitalization of a gray tone scale with more than two levels in one step. Furthermore, because of vignetting effects the binary black and white prints also show a strong distortion of the image contents. The solution to these problems is described in [3].
After digitizing all maps were fitted to the Gauss-Krüger coordinate system and in this way to each other. This occurred according to the same procedure which was used to rectify the thermal-image and which will therefore be described in detail in section 4 of this paper. Finally, with the corner points having been given in Gauss-Krüger coordinates, similar "windows" were cut from the individual maps and digitally superimposed; this served as a quality control of the processing procedure. Fig. 4 shows the relief map superimposed with the urban built-up distribution and water network which were produced in this way (the former represents only the German part of the territory investigated.

4. Processing the thermal-image

4.1 Geometric adjustment to the Gauss-Krüger coordinate network

4.1.1 Theory

The geometric rectifications in this investigation have been carried out by the interpolation method. This method assumes that between a distorted scene V and a reference-image R there exists a functional dependence

$$R = F\ (V)$$

and that a rectified scene E can be produced by the operation F on V, thus

$$E = F\ (V)$$

The parameters for F are derived from R and V by the control point method, i.e., corresponding control points are sought in the reference-image R and the distorted scene V and their respective coordinates are determined in both coordinate systems. This alignment results in a transformation equation, by which all points of the distorted scene can be related to the reference-image.

4.1.2 Definition of the control points

In order to achieve the highest possible degree of precision the determination of the control points proceeds in two steps. First, the thermal-image is corrected with respect to water-networks and forest distribution ("rough" rectification). From this corrected image, which already represents a good geometric approach to the topographical map, the control points for the final rectification are determined using Gauss-Krüger coordinates ("fine" rectification).

The determination of the control points for the first step of rectification has been carried out on the DIBIAS-monitor screen. Here the thermal-image as well as the digitized and pointwise correlated forest distribution and water-network maps were deposited in the image memory of the system. In this way one can rapidly compare the images and easily identify their corresponding structures. As an auxilary aid in the present investigation a relief map was used additionally.

Seven of the 17 control points used for the "rough" rectification lie on the Rhine river, 2 on prominent corners of forests, and 8 in the bends of valleys and valley confluences of the Highlands.

In order to achieve an average residual error of less than one pixel in the "fine" rectification, it has been attempted on the basis of the topographical overview map, scale 1:200 000 (TÜK 200), to determine the coordinates for 50 to 100 control points with an error of less than 600 m. This requirement means the determination of these points on the map with an accuracy of 3 mm. For doing this the "rough" rectified images have been projected onto the corresponding map sections. By shifting the maps on a magnetic wall, the structures which correspond to the recognizable patterns in the thermal-image - namely, relief, forest distribution, water-network, urban built-ups - were assigned in sub-regions of 20 to 40 km in diameter. Corresponding details of the thermal-image and the map were then identified in these partial-regions.

The 86 detected control points, for which a definition within the afore mentioned margin of error was possible, are distributed among the different classes according to the following list:

Bodies of water: 5 points

Urban built-up areas: 5 points

Land-use boundaries: 18 points

Relief: 51 points.

It should be noticed that for all defined categories or classes only a few of many geographically equivalent situations were recorded in the thermal-image. This is due to smearing in mixed signatures caused by averaging the temperatures of the different objects which contribute to the pixel. From this point one can derive two consequences:

Firstly the fact of this "smearing" reinforces trust in those control points which were finally selected. Exactly those situations have been captured in which the phenomenon producing the signal was located centrally in the respective pixel. Secondly, it is to be expected that some of the control points which were employed here will not always be useful for the rectification of other images of the same territory, even if they are taken at the same time of day. This is because due to different arrangement of the pixels, the same geographic phenomenon can be reproduced clearly in one image but less prominent in another one.

4.1.3 Quantitative results and precision of the procedure

With the control points thus defined, the entire scene (linear and quadratic polynominals) as well as different selected parts of it have been rectified with respect to the format of TÜK 200 in several computing runs. The table in Fig. 5 shows that for the "rough" rectification the best results reveal a r.m.s. error of somewhat more than 1 000 m in both the line and column direction, for the "fine" rectification the values are 618 and 606 m in line and 468 and 462 m in the column direction. The insignificant difference between the residual errors of the linear and quadratic approaches - 618 and 468 m <u>vs.</u> 606 and 462 m respectively suggests that, with regard to the size of the investigated area (about 300 x 150 km), the increased time-consumption of the quadratic approach (35 min. calculating time <u>vs.</u> 18 min. for the linear approach) is not yet compensated by the relatively small gain in efficiency.

The r.m.s. errors from the individual rectifications of the three TÜK-plates are with one exception all significantly smaller that one pixel of the original data. The somewhat better values for the plates CC 7910 (Freiburg-North) and CC 8710 (Freiburg-South) can well be attributed to the investigators' long experience with this area, especially by the previous work with aircraft scanner thermal imagery, which facilitates the selection of control points in this region.

The fact that after the linear rectification no more essential systematic distortions are present in the image is shown in the r.m.s. vector diagrams of the individual control points (Fig. 6a, 6b): the vectors in the different parts of the image exhibit no specific tendencies.

This argumentation using r.m.s. errors and vector-diagrams of r.m.s. errors contains a high degree of abstraction and, in addition to that, offers no compelling proof of the quality of a rectification since it would hide, for example, a systematic additive error (translation). Therefore, in Fig. 7 and 8 the results of the rectification will be presented by using images.

I. "Rough" Rectification

Area	Reference map	control points No.	Determination	Solution approach	Size of the pixels Original (m)	Image (m)	r.m.s. x-axis bi	m	y-axis bi	m	Calculating Time
entire scene[1]	forest	10	monitor screen	linear	1200	1200	1.5	1800	12.6	15000	
	water, network	10	monitor screen	linear			1.2	1440	2.95	3540	
	relief	10	monitor screen	linear			1.3	1560	1.98	2376	
	1:1 000 000	11	monitor screen	linear			0.9	1080	1.1	1320	
	1:2 000 000										
entire scene (northern portion)	1:2 000 000	9	monitor screen	linear	600	600	1.8	1080	2.05	1230	
entire scene (southern portion)	1:2 000 000	10	monitor screen	linear	600	600	2.5	1500	1.99	1194	
II. "Fine" Rectification											
entire scene	TÜK 200	50	GK[2]	linear	600	600	1.03	618	0.78	468	18 min.
entire scene	TÜK 200	50	GK	quadratic	600	600	1.01	606	0.77	462	35 min.
CC 7110 (Mannheim)	TÜK 200	14	GK	linear	600	125	1.04	624	0.74	444	13 min.
CC 7910 (Freiburg-North)	TÜK 200	17	GK	linear	600	125	0.98	588	0.66	396	13 min.
CC 8710 (Freiburg-South)	TÜK 200	17	GK	linear	600	125	0.87	522	0.76	456	12 min.

[1] entire scene = Upper Rhine Region with surrounding highlands. [2] GK = Gauss-Krüger coordinates.

Fig. 5: Numerical results of the geometrical rectification

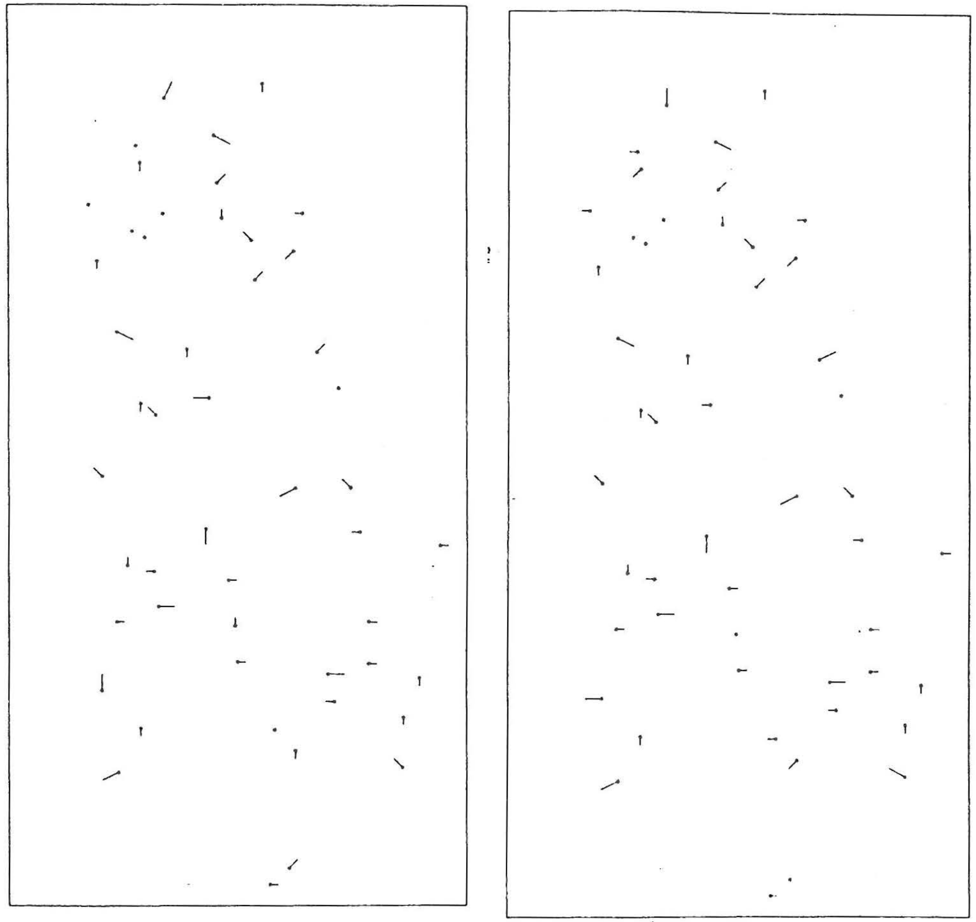


Fig. 6 a Diagram of the r.m.s. vectors in the "fine" rectification of the entire scene; left, quadratic and right linear. For a clear representation the vector length have been stretched by a factor of 8 relative to the scale of the drawings.

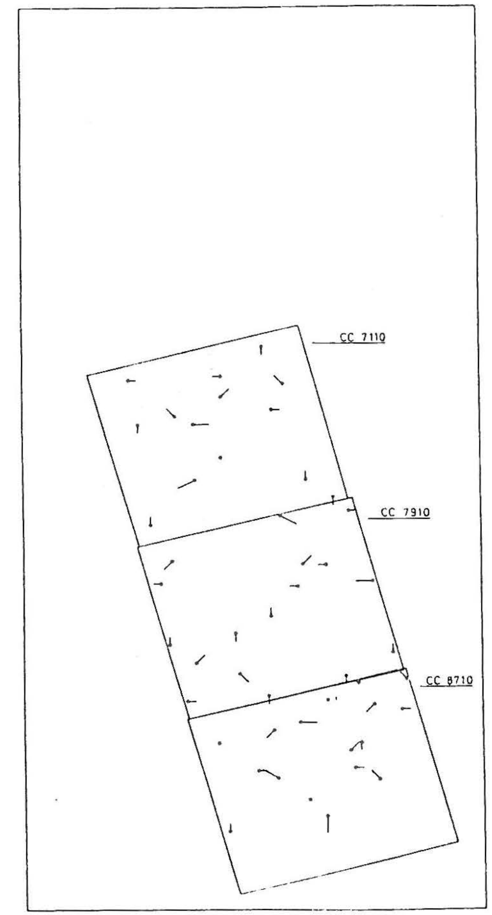
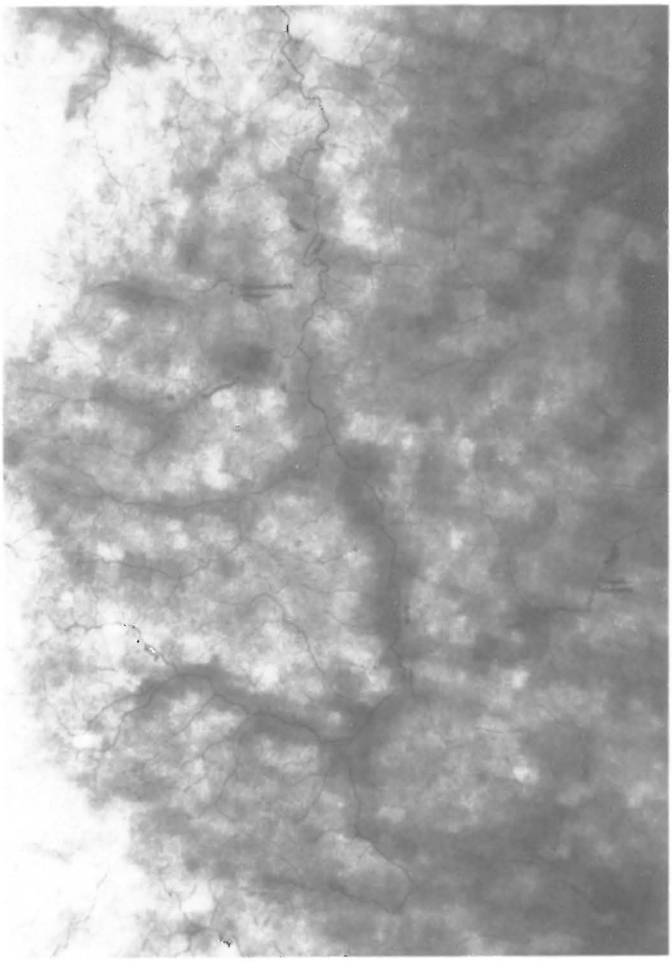


Fig. 6 b Diagram of the residual vectors in the "fine" rectification in accordance with TÜK 200 map plates (cf. the last, 3 lines in Fig. 8 a). As in Fig. 8 b the vector lengths have been increased by a factor of 8.

Fig. 7: HCMM thermal image showing drainage area of the river Murg in the northern part of the Black Forest after the second step of rectification. The superimpased water-network is from the Topographical Map 1:200 000, sheet CC 7910 (Freiburg-Nord).



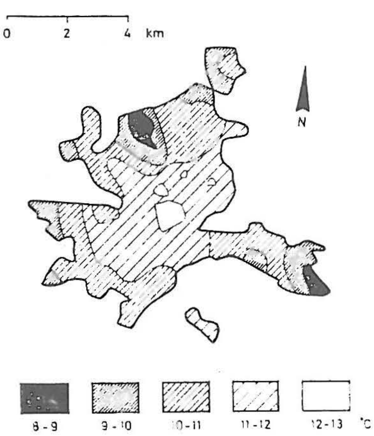


Fig. 8 a: Surface-temperature distribution within the city of Freiburg on 5/30/79, 2:13 GMT (preliminary calibration), as revealed by the thermal-image following "fine" rectification and "smoothing" of the pixel edges.

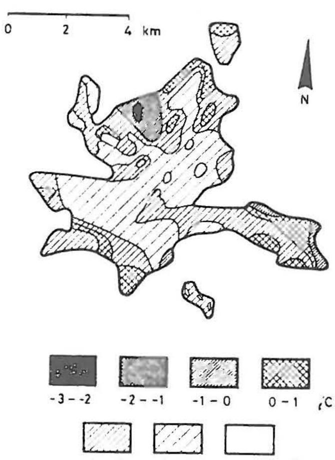


Fig. 8 b: Surface-temperature distribution within Freiburg, taken from an aircraft scanner thermal image form 4/1/76 3:40 GMT, 4 000 m height above ground, resolution of the original pixels: 10 m.

4.2 Calibration

The figures of this paper represent all HCMM-Data as temperature images in Celsius degrees. This has been used, because of better clearness, although the calibration of the data is not yet sure depending on several reasons (see [1]and[3 , p. 27])

5. The construction of the multi-channel scene

As a result of the processing steps described above the following spatially correlated, digitized, and rectified image-information from the investigated area was derived:

- o the HCMM-night-infrared-image-data with calibrated gray values;
- o the HCMM-night-infrared-image-data with calibrated gray values which were also adapted to the temperature pseudo-colour-scheme;
- o the network of urban built-ups;
- o the forest distribution;
- o the relief for the area represented in map CC 7110
- o and the classified image data described in section 2.

By means of the ME-module (Merge-Modul, cf. [5]) the individual scenes have been transformed into two multi-channel scenes: one for the entire area under investigation and a second for the region represented in CC 7110.

The content of the various channels in the first multi-channel scene is sketched in Fig. 9.

A pixel $\underline{g}$ of this scene is thus a vector in six dimensions $(g_1, g_2, g_3, g_4, g_5, g_6)$; the vector components correspond to the following categories:

g_1:	= 230	elevation	0 - 200 m
	= 180	"	200 - 400 m
	= 130	"	400 - 700 m
	= 80	"	700 - 1000 m
	= 30	"	> 1000 m
g_2:	= 0	urban built-up	
	= 255	no urban built-up	
g_3:	= 0	forest	
	= 255	no forest	
g_4:	= 0	body of water	
	= 255	no body of water	

g_5: $0 \leq g_5 \leq 255$ HCMM-night-IR-data, calibrated

g_6: $0 \leq g_6 \leq 255$ HCMM-night-IR-data, calibrated and adapted to the temperature pseudo-colour-scheme.

The second multi-channel scene overlays a portion of the map CC 7110. It was produced in a procedure similar to the one described above and consists of the following eight channels:

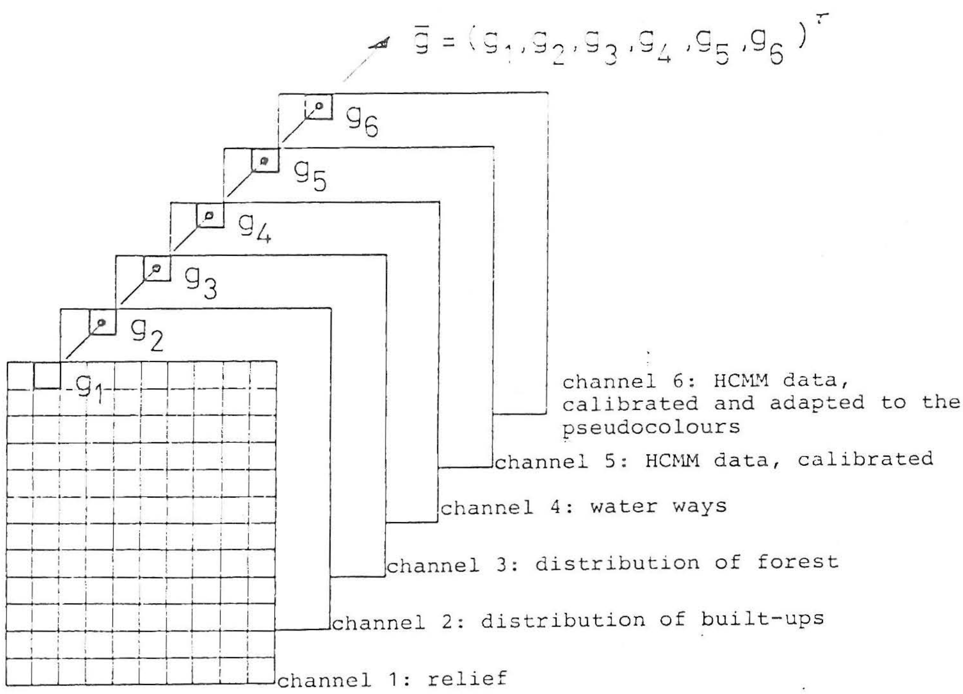


Fig. 9: Data structure of the multi-channel scene for the whole area under investigation.

K_1 LANDSAT classification according to section 2.

K_2 HCMM-night-IR-data, calibrated.

K_3 HCMM-night-IR-data, calibrated and adapted to the temperature pseudo-colour-scheme.

K_4 HCMM-night-IR-data, calibrated, averaged, and adapted to the temperature pseudo-colour-scheme.

K_5 relief

K_6 urban built-up

K_7 water-ways

K_8 forest distribution.

6. Example of evaluation

The data structures described in chapter 5 allow the combination of the different channels with their special information. A diversity of questions can be investigated with respect to the dependence of the surface temperature on other surface characteristics. Thus these data structures are useful aids for the investigation of the "thermal conditions of different parts of the landscape" [2]. In the following one example of evaluation will be presented.

Surface temperature and land-use

For the region of the topographical map CC 7110 (1:2 000 000, Mannheim), for which the Landsat derived land-use classification has been integrated into the data structure, statistics of the surface temperature for each land-use type can be calculated. Without regarding the influence of the relief, this evaluation has been calculated for the elevation level 0 - 200 m, according to the elevation of the Rhine valley (Fig. 10).
For the statistical analysis of the evident correlation of the surface temperature with the type of landuse, the whole region of CC 7110 has been overlaid with a grid of 5 x 5 km. For each of these squares the distribution of the different land-use classes can be calculated. This data may be used to estimate the change in night-time surface temperatur occurring, when the land-use pattern is modified (see fig. 12).

increase 20 % → / decrease 20 % ↓	built-up areas	open land	forest	vineyards	water
built-up areas	-	-0,552	-0,245	-0,054	2,038
open land	0,552	-	0,307	-0,498	2,590
forest	0,245	-0,307	-	0,191	2.283
vineyards	0,054	-0,498	-0,191	-	2,092
water	-2,038	-2,590	-2,283	-2,092	-

Fig. 11: Modification of night-time surface-temperatures (^{o}C bzw. K), caused by 20 % - changes in land use. Calculated for the Upper Rhine Valley near Mannheim on the basis of HCMM and LANDSAT-data.

8. References

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