COMMISSION OF THE EUROPEAN COMMUNITIES
JOINT RESEARCH CENTRE
ISPRA ESTABLISHMENT (ITALY)

(E80-10332) HCMM SATELLITE FOLLOW-ON INVESTIGATION NO. 025: SOIL MOISTURE AND HEAT BUDGET EVALUATION IN SELECTED EUROPEAN ZONES OF AGRICULTURAL AND ENVIRONMENTAL INTEREST (TELLUS (Joint Research Centre of

N80-32823

Unclas
G3/43 00332

HCMM SATELLITE FOLLOW-ON INVESTIGATION No. 025
SOIL MOISTURE AND HEAT BUDGET EVALUATION IN SELECTED EUROPEAN ZONES OF AGRICULTURAL AND ENVIRONMENTAL INTEREST (TELLUS PROJECT)

Second Progress Report

September 1st, 1979 - March 31st, 1980

TABLE OF CONTENTS

Summary

The TELLUS Project is progressing quite satisfactorily. HCMM satellite data are now routinely being processed and shipped to the JRC Ispra for distribution, even if with some delay. Production and dissemination of HCMM data received by the European station at Lannion has started.

The Joint Flight Experiments, funded and organized in the UK, France and Italy, have raised much interest in the application of the thermal inertia method for the determination of soil moisture and evapo-transpiration. The first computer-aided classifications of different soil moistures remotely sensed by aircraft have been published. Since further laboratories did approach the JRC for collaboration, a Joint Measuring Campaign has been carried out in Germany with participation of several European field teams, including simultaneous measurements from satellite and aircraft and extensive ground truth at the same site.

Besides the TERGRA and TELL-US models a simple one-dimensional analytical model based on the Fourier analysis of the various fluxes involved in the thermal behaviour of soils was developed. It gave a reasonable agreement with results calculated by the TERGRA algorithm.
The TELL-US model has been adapted to surfaces covered by dense vegetation giving the SEAL (Simplified Evaporation Algorithm). An operational model (TELOP) is now available, based on a correlation between cumulative ET, net radiation and soil moisture in the root zone weighted for root density. It was tested successfully on grassland.

The first applications of satellite thermal data to the evaluation of ET were made in the Netherlands and in France. In the Netherlands it was attempted to map ground-water levels. On the French test-area of Crau, thermal data from NOOA-5 and HCMM were compared for the dry and irrigated plots.

Superpositions of HCMM thermal data on other satellite imagery and thematic maps was made in Germany. The system permits to create a multi-channel data structure for the region under investigation, the channels being one or more HCMM data sets (multitemporal analysis) and thematic information (land use, topography, etc.). On this basis a first evaluation of the usefulness of HCMM thermal data of the anthropogenic heat release of built-up areas was carried out for the city of Freiburg (Germany).
Finally a number of attempts is being made to validate the calibration of the HCMM IR-channel by comparing ground measured surface temperatures with those given by the HCMR. The part of this work already defined and finished is documented in the TELLUS NEWSLETTERS No. 11, 12, 13, 14, 15 and 16 which are annexed to the present status report.

1. INTRODUCTION

TELLUS is a remote sensing project centered around the satellite EXPLORER-A, bearing the sensors HCMM (Heat Capacity Mapping Mission). The special feature of this satellite measuring the temperature cycling (N/D) of objects on the Earth surface makes it suitable for hydrological and/or geological prospection.

The main objective of TELLUS is to demonstrate that such temperature cycling can be related to moisture content in bare and vegetation-covered soils and to anthropogenic heat release. The study of the influence of natural modifications on the regional heat budget is another important subject of investigation.

The objectives of the proposed programme, while partially fulfilling a number of specific EC needs in the policy of agriculture and the environment, also correspond to the specific research objectives of the participating Institutes.

The role of the JRC in the TELLUS project consists of two distinct parts:

- A coordinating activity for the contribution from national institutes (co-investigators) working on different test sites and topics (see the 1st Progress Report). This coordination includes the present liaison with NASA, Space Goddard Flight Center.

- An experimental activity, essential in itself, on test site No.1, and organization and participation in Joint Flight Campaigns. In addition the JRC is dispatching, processing and interpreting data received from NASA/GSFC and ESA/EARTHNET.

2. TELLUS FRAMEWORK

The main lines of TELLUS' organization and objectives are here reported. This will help in better understanding who did, why and where during the reporting period. For a more detailed information please look it up in the 1st Progress Report (Chapt.s 2, 3 and 4).

2.1. The Co-investigators

The names and abbreviations of the University Departments and Institutes participating in the TELLUS mission are listed in Table 1. Coinvestigators framework consists of six groups. The JRC Ispra and some EC Directorates General make up the PI's leading group.

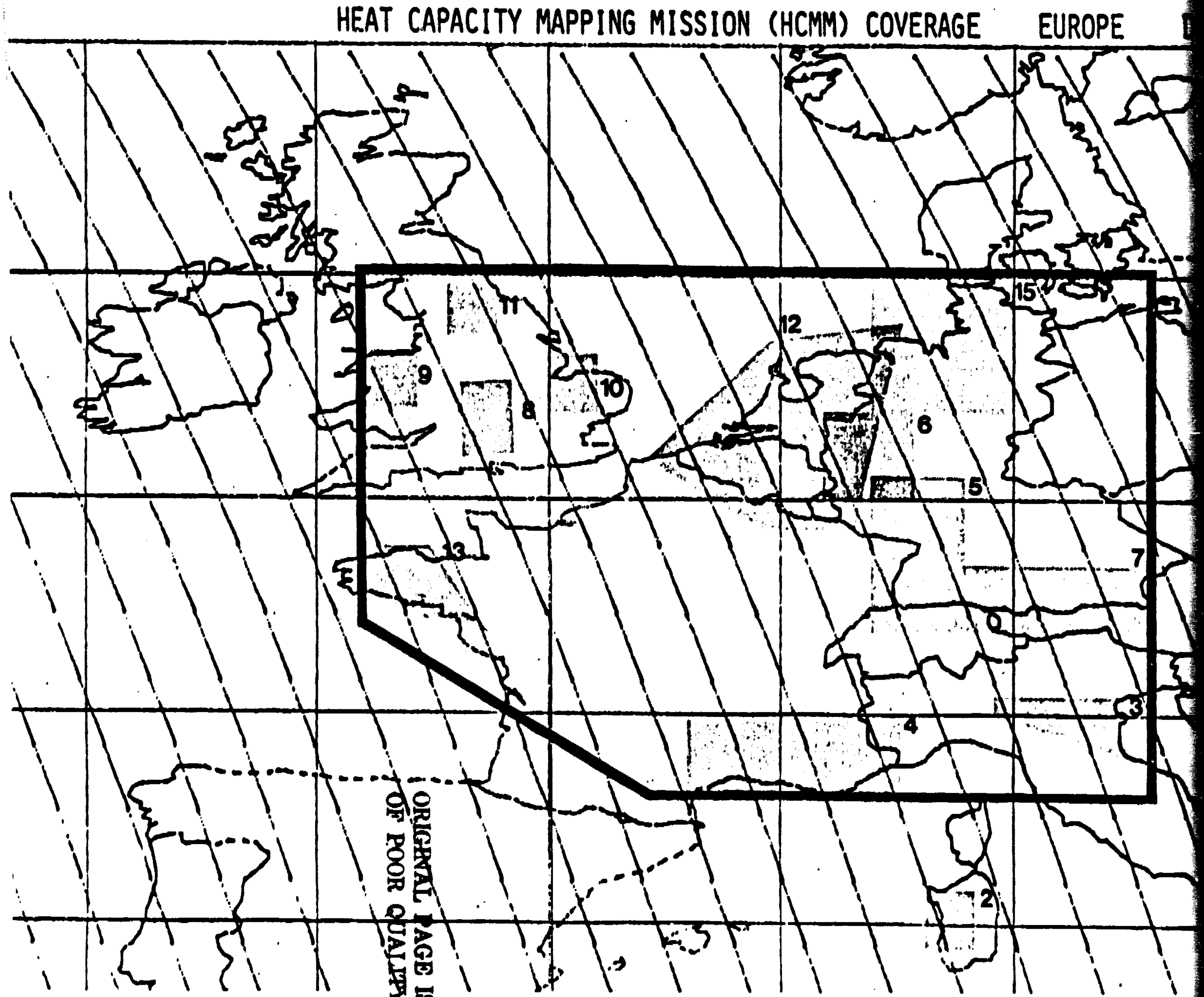
2.2. The Test-sites

Geographic as well as technical considerations led to arrange in five groups the thirteen test-sites as originally proposed by the Coinvestigators. No particular test-site was proposed by the JRC Ispra within TELLUS. His research staff works in collaboration with TELLUS coinvestigators on their national test-sites. A test-site coordinator was designated for each group according to the Institutes involved. Arrangement in groups of TELLUS Test-sites is reported in Table 2. Fig. 1 shows the distribution of the test-sites proposed by Coinvestigators within the overall test-site "Europe" which was agreed by JRC and NASA (boundary in brackets).

2.3. Mission's objectives

According to the interest of the EC Commission and the research proposals made by the Coinvestigators, there are three main thematic lines of investigation:

1. Evaluation of evapotranspiration and moisture content of bare soils and of soils covered by vegetation



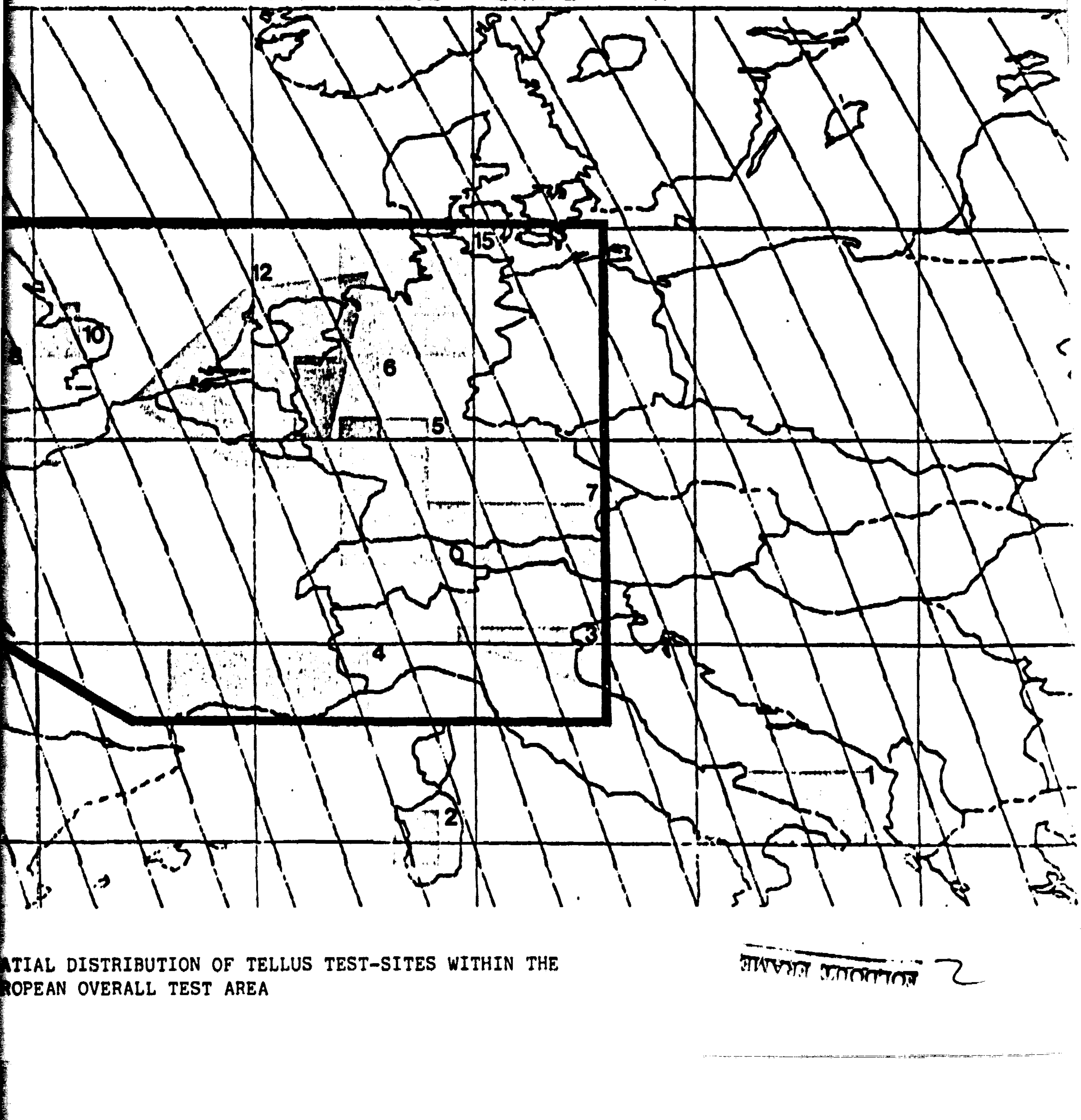
FOLDOUT FRAME

Fig. 1 SPATIAL DISTRIBUTION OF TELLUS TEST-SITES WITHIN THE EUROPEAN OVERALL TEST AREA

3

. QUALITY

MAPPING MISSION (HCMM) COVERAGE EUROPE DAY



TIAL DISTRIBUTION OF TELLUS TEST-SITES WITHIN THE
ROPEAN OVERALL TEST AREA

FOLDOUT FRAME 2

QUALITY

TABLE 1: LIST OF ORGANIZATIONS AND INSTITUTES PARTICIPATING IN THE TELLUS PROJECT (HCM-025)

TEST-SITE COORDINATORS (TSC'S)	CO-INVESTIGATORS (COI'S)	ORGANIZATIONS AND INSTITUTES	
		DIRECTORATES OF THE EUROPEAN COMMUNITIES	
		- Directorate General for Agriculture, Brussels	DG-VI
		- Directorate General for Research, Science and Education, Brussels	DG-XII
		- Joint Research Centre, Ispra	JRC
		- EEC Delegation, Washington	DG-I/WD
		NATIONAL ORGANIZATIONS AND INSTITUTES	
Feddes R.A.		Belgium	
	D'Hoore J.M.	- Fakulteit der Landbouwwetenschappen, Katholieke Universiteit, Leuven	KUL/LBB
		Denmark	
	Eckardt F.E.	- Institutet for Okologisk Botanik, University of Copenhagen	UK/IOB
Goillot Ch.		France	
	Goillot Ch.	- Service de Télédétection, INRA Versailles	INRA/ST
	Barloy E.	- Station d'Amelioration des Plantes, INRA Rennes	INRA/SAP
	Seguin B.	- Sation de Bioclimatologie, INRA Montfavet	INRA/CRASE/SE
	Perrier A.	- Station de Bioclimatologie, INRA Versailles	INRA/SB
	Becker F.	- Groupe de Recherches en Télédétection Radiométrique, Université de Strasbourg	ULP/GRTR
Gossmann H.		Germany	
	Gossmann H.	- Geographisches Institut der Universität, Freiburg	UF/GI
	Van der Ploeg R.	- Institut für Bodenkunde und Waldernährung	UG/IBW
Caliandro A.		Italy	
	Borriello L.	- Centro Studi Applicazioni Tecnologie Avanzate, Bari	CSATA
	Cavazza L.	- Istituto di Agronomia Generale e Coltivazioni Erbacee Università di Bologna	UBO/IAGCE
	Milella A.	- Istituto di Agronomia e Coltivazioni Arboree, Università di Sassari	USS/IACA
	Caliandro A., Pacucci G.	- Istituto di Agronomia e Coltivazioni Erbacee, Università di Bari	UBA/IACE
	Maracchi G.	- Istituto di Agronomia Generale e Coltivazioni Erbacee, Università di Firenze	UFI/IAGCE
	Posa F.	- Istituto di Fisica, Università di Bari	UBA/IF
	Marcolongo B.	- Istituto di Geologia Applicata, CNR Padova	IGA
	Pietracaprinn A.	- Istituto di Mineralogia e Geologia, Univ. di Sassari	USS/IMG
	Lechi G.M.	- Istituto per la Geofisica della Litosfera, CNR Milano	IGL
	Tombesi L.	- Istituto Sperimentale per la Nutrizione delle Piante, Roma	ISNP
	Rosini E.	- Ufficio Centrale di Ecologia Agraria, Roma	UCEA
Feddes R.A.		Netherlands	
	Feddes R.A.	- Instituut voor Cultuurtechniek en Waterhuishouding, Wageningen	ICW
	Van Ulden A.P.	- Koninklijk Nederlands Meteorologisch Instituut, De Bilt	KNMI
Mc Culloch J.G.		United Kingdom	
	Kirkby M.J.	- Department of Geography, University of Leeds	UL/DG
	Savigear R.A.G.	- Department of Geography, University of Reading	UR/DG
	Mc Culloch J.G.	- Institute of Hydrology, Wallingford	IHW

2. Study of the interaction between natural phenomena and mesoscale heat budget

3. Man-made changes and their impact on regional heat budgets

3. DATA RECEPTION AND DISTRIBUTION

In order to simplify the comments to be done, we recall that the HCMM data received at the JRC are classified as follows:

1. Data from NASA/GSFC origin
2. Data from ESA/EARTHNET origin

For more details you are kindly requested to look up in 1st. PR, Chapt. 5.

3.1. NASA/GSFC data delivery

3.1.1. <u>Situation at Aug. 31st, 1979</u>

Beside HCMM preliminary data (some transp.s and tapes on Chesapeake Bay, US) only Standing Orders (DVIS, DIR, NIR) on form of 24x24 cm neg. transp.s were received at the JRC Ispra. No Retrospective order (RO) on form of CCT was received.
Only scenes (~ 20%) of the 81D + 81N consecutive scenes of the Priority Processing List (PPL), requested by JRC to GSFC early 1979, had arrived. Only one consecutive N/D data was received.
On the other hand many other 50 scenes were received by the JRC in the above period. Table 8 of the 1st PR, resumes the overall situation of GSFC data received by JRC Ispra and distributed to COIs. One can see that UK COIs were particularly ill-served also for cloud cover reasons.

3.1.2., <u>Situation at March 31st. 1980</u>

3.1.2.1. Standard Order data

SO data have come to JRC for a total of 240 N and D orbits, corresponding to 262 N scenes and 300 D scenes, with a total of 83 processings.

Table 2 : TELLUS test sites, arranged in groups.

Test-Site Group	Test Site	N°
ITALY	Puglia and Basilicata*	1
	Sardegna	2
	Emilia	3
FRANCE	Bouches du Rhône	4
	Bretagne	13
GERMANY	Rhine Valley	5
	Rhine Valley	6
	Northern Alps	7
	Northern Germany	15
UNITED KINGDOM	England	8
	Wales	9
	England	10
	England	11
BENELUX	Benelux	12
DENMARK	Greenland**	14

*) Basilicata proposed by UR/DG

**) No HCMM receiving station

However the PPL has been still poorly satisfied: ~ 50% of priority request only delivered. In fact 78 D and N orbits have been received at JRC Ispra (see Tables 3 and 4). The reasons can be the following:

a. The cutting up of orbits seems to be done at random: we happened to receive northern part of orbit when asking southern part and viceversa.

ex.: we received

date of tracking	track.no.	Scene delivered
May 22, 1978	9N1, orbit 380	01.23.0 (Germany)

where as we asked for (South Italy) and Madrid reception is from 01.22. to 01.33 which means we might have got southern map.

b. Some tracks have two N orbits or two D orbits overflying the European test-sites. When asking for the first one, we received the second one.

ex.: we received

date of tracking	track	Scene delivered
May 22.10.1978	9N2, orbit 381	02.57 - 02.58

where as asking only 9N1.

c) The reprocessing of the same Scene is not uncommon: Scenes processed several times have not always the same geographic coordinates which makes difficult the CCT request and filing of the scene.

Ex.:

Processing data	Tracking data	Geographic coordinates indicated on trasparencies
15 Aug. 1979	23 May 1979	N 39.29 E 013.15
11 Sept. 1979	23 May 1979	N 38.49 E 013.26
15 Aug. 1979	30 May 1979	N 42.22 E 004.37
14 Sept. 1979	30 May 1979	N 44.55 E 003.47
30 April 1979	20 Febr. 1979	N 43.56 E 004.27
10 May 1979	20 Febr. 1979	N 46.54 E 004.47

d. The photographic representations are identical (cloud shapes correspond) but day, hour of scenes are different. This particular verification has been possible because the scenes were included in the same package; but what about scenes in different packages?

ex.:

Processing date	Tracking date	Coordinates indicated
26 Sept. 1979	28 May 1978	N 49.26 E 008.13
28 Sept. 1978	13 Sept. 1978	N 51.05 E 008.26

e. Images were processed and announced but not included in packages:

ex.:

NASA Ship.t of 17.10.79 announced:

images No.ident. A A0064 01 3303
A A0064 01 3503

but the package did not contain these scenes.

No relevant changes in the data quality to be observed from last interim report.

TABLE III

Priority Processing List (PPL) and shipments received at JRC

AL	Date	Test-sites	Track	AL	Date	Test-sites	Track
22 D	18.05	2,3 I	5 (1978)	108 ND	12.08	3 F	11 (1978)
24 D	20.05	3 F	7				
26	22.05	1 I	9	111	15.08	1 I	14
27	23.05	3 I	10	113 D	17.08	3 F	16
29	25.05	3 F	12	114 D	18.08	3 GF	1
31	27.05	1 I	14	118 ND	22.08	2,3 IG	5
33 ND	29.05	3 G	16	122 D	26.08	1 I	9
34 ND	30.05	3 G	1	123 N	27.08	3 I	10
35 NN	31.05	3 FD	2d	124 D	28.08	3 I	11
38	03.06	2 I	5	127	31.08	1 I	14
42	07.06	1 I	9d	129 ND	02.09	3 F	16
43	08.06	3 I	10	130 ND	03.09	3 UKF	1
45 D	10.06	3 F	12	131 ND	04.09	3 UK	2
47	12.06	3 I	14	134 D	07.09	2,3 I	5
54 D	19.06	2,3 I	5	138 ND	11.09	1 I	9
				139 N	12.09	3 I	10
55 ND	20.06	3 G	6	141 ND	14.09	3 F	12
58 N	23.06	1 I	9	142 ND	15.09	3 F	13
				143 N	16.09	1 I	14d
59 D	24.06	3 I	10	147	20.09	3 UK	2
63	28.06	1 I	14	150 D	23.09	3 I	5
70 ND	05.07	2,3 I	5	154 D	27.09	1 I	9
72	07.07	3 UK	7	155 N	28.09	3 I	10
73 N	08.07	3 UK	8	159	02.10	1 I	14
74 N	09.07	1 I	9	166	09.10	3 G	5n
75 ND	10.07	3 I	10	168 D	10.10	3 G	6n
				170 D	13.10	3 G	9
77 N	12.07	3 F	12d	172 D	15.10	3 GF	11n
79	14.07	1 I	14d	183 D	25.10	2	5
81 N	16.07	3 IF	16				
82 ND	17.07	3 B	1	184 D	27.10	3 F	7
86 D	21.07	2,3 I	5	185 D	28.10	3 F	8
87	22.07	3 F	6	187 D	30.10	3 G	10
90	25.07	1 I	9d	193 D	05.11	2 I	16
91 N	26.07	3 I	10d	195 ND	07.11	3 F	2n
95	30.07	1 I	14d	198 ND	10.11	2,3 I	5
96 $N_1 D_B$	31.07	1 IB	15	199 ND	11.11	3 G	6
100	04.08	1 I	3d	200 ND	12.11	3 F	7
101 N	05.08	1 I	4d	205 N	17.11	3 F	12
102 N	06.08	2,3 I	5	216 D	28.11	3 UK	7
106 N	10.08	1 I	9	225 D	07.12	3 G	16
107 N	11.08	3 I	10	227 D	09.12	3 F	2n
				232 D	14.12	3 F	7n
				274 D	25.01	3 G	1 (1979)

Symbols and abbreviations:
- AL after launch (no. of days)
- d tracks not received by MADRID station (day)
- n tracks not received by MADRID station (night)
- ND shipment received night and day

Test-sites for NASA PPL request:
- 1: Basilicata, Puglia
- 2: Sardegna
- 3: Rest of Europe

- B : Benelux
- G : Germany
- F : France
- I : Italy
- UK: United Kingdom

TABLE IV

PRIORITY PROCESSING LIST

MONTH	REQUESTS										RESPONSES								FAILED			
	D		BNL		F		UK		I		D		BNL		F		UK		I		TRACKS	
78	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D
May	3	3			2	2			4	4	3	2			1	1				1		1
June	1	1			1	1			7	7	1	1				1			1	2		1
July			2	2	2	2	2	2	9	9			2	2	1		1		5	9		5
August	1	1			4	4			10	10	1	1			1	3			5	2		2
September					5	5	3	3	7	7					4	4	1	2	4	4		1
October	5	5			2	2			2	2		4				2				1	3	
November	1	1			4	4	1	1	3	3	1	1			3	2		1	1	2		
December	1	1			2	2						1				2					2	
Jan 79	1	1										1										
TOTAL	13,13		1,1		22,22		6,6		42,42		6,11		2,2		10,15		2,3		16,15			

3.1.2.2. Retrospective Order data

Retrospective Order data (DVIS, DIR, NIR) under the form of 81 CCTs were requested by the TELLUS Coinvestigators. 46 of them were already received by the JRC and distributed.

3.2 ESA/EARTHNET data delivery

3.2.1. Quick Looks

CMS Lannion started the production of QL negative transparencies for the whole tracking of the station in May 1979.

These quick-look transparencies have been regularly dispatched from Lannion to the various test-site coordinators as well as to the JRC Ispra.

Up to now TELLUS received a total of 395 orbits.

Production of QLS data is up to date.
Their quality is excellent. NASA has agreed that the geometric and radiometric correction routines to be used at Lannion are satisfactory.

In Fig. 2 the distribution of QLS among the Test-site coordinators is reported.

3.2.2. Retrospective Order Data (RO)

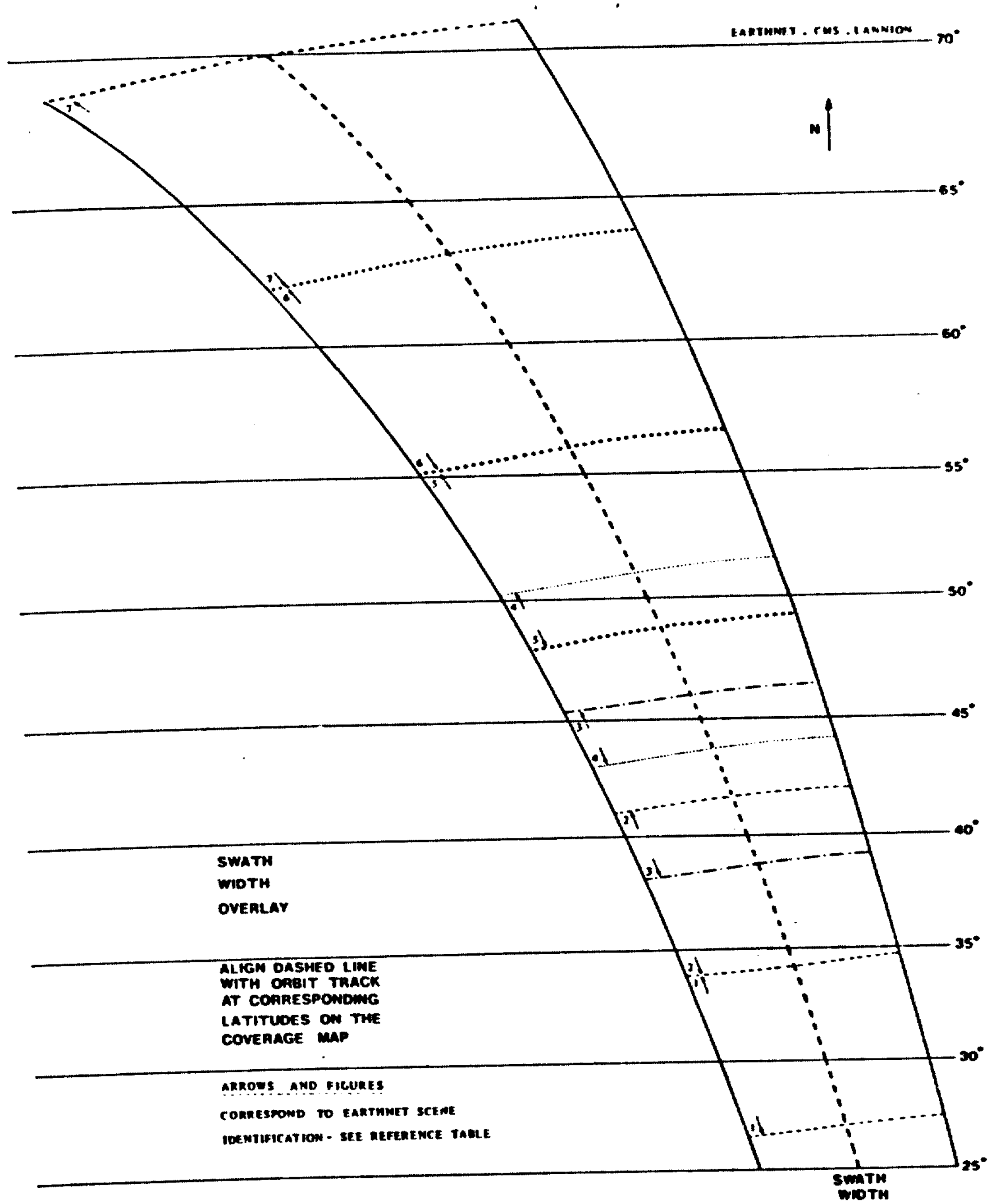
are requested after reception of QLS. This request is made according to a standard cutting up of the orbits (see Fig. 3a and 3b) and runs normally.

Fig. 2 shows the flow diagram of the ESA/EARTHNET Retrospective Order Request and distribution.

This standard cutting up of the orbits seems to be satisfactory, chiefly if we compare it to the NASA random distribution of scenes along the tracks.

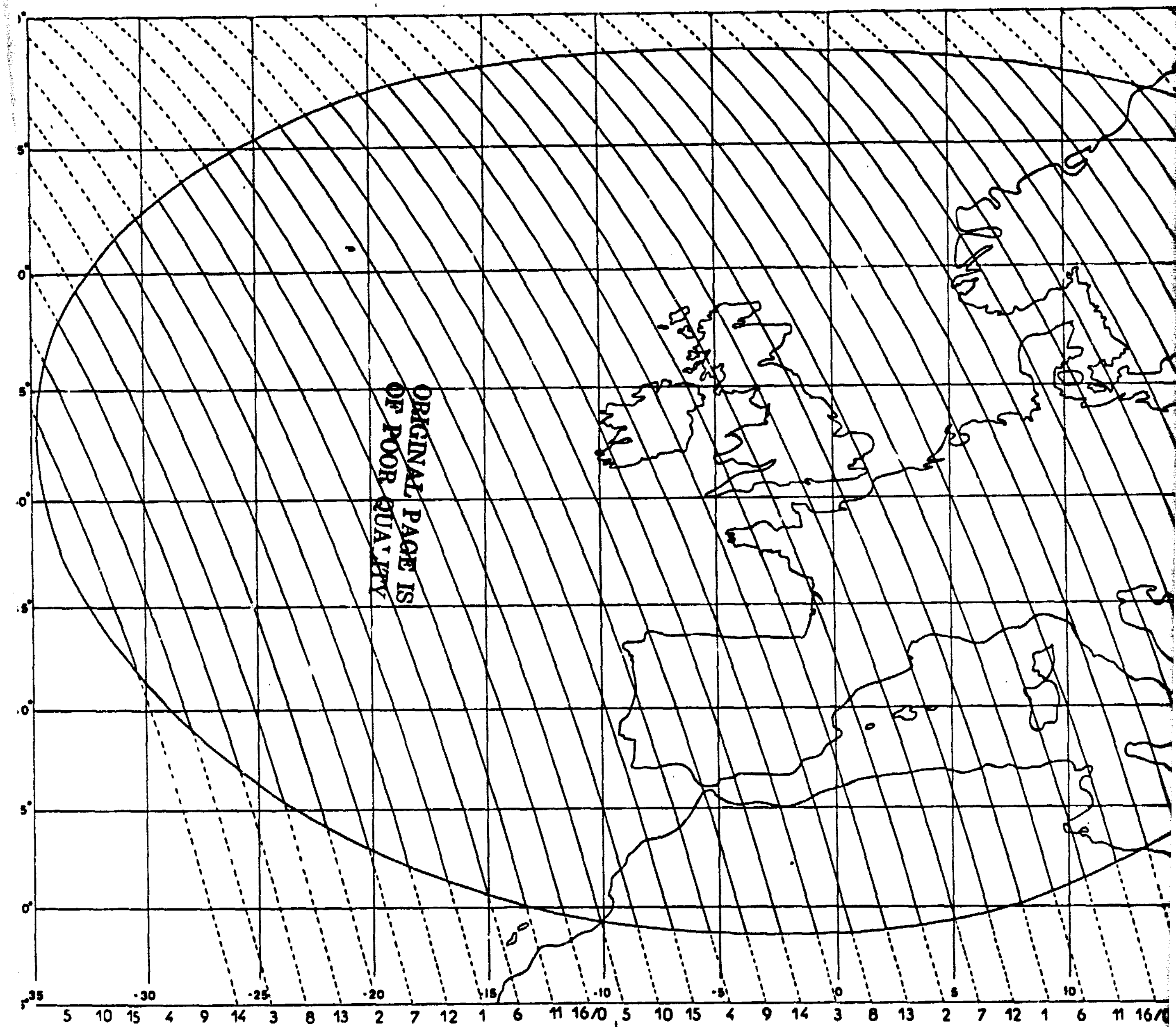
Coinvestigators recently asked for 47 CCTs. 8 of them have already been received at JRC Ispra.

HCMM COVERAGE EUROPE DAY



3 b

HEAT CAPACITY MAPPING MISSION (HCMM) COVERAGE EUROPE DAY



FOLDOUT FRAME

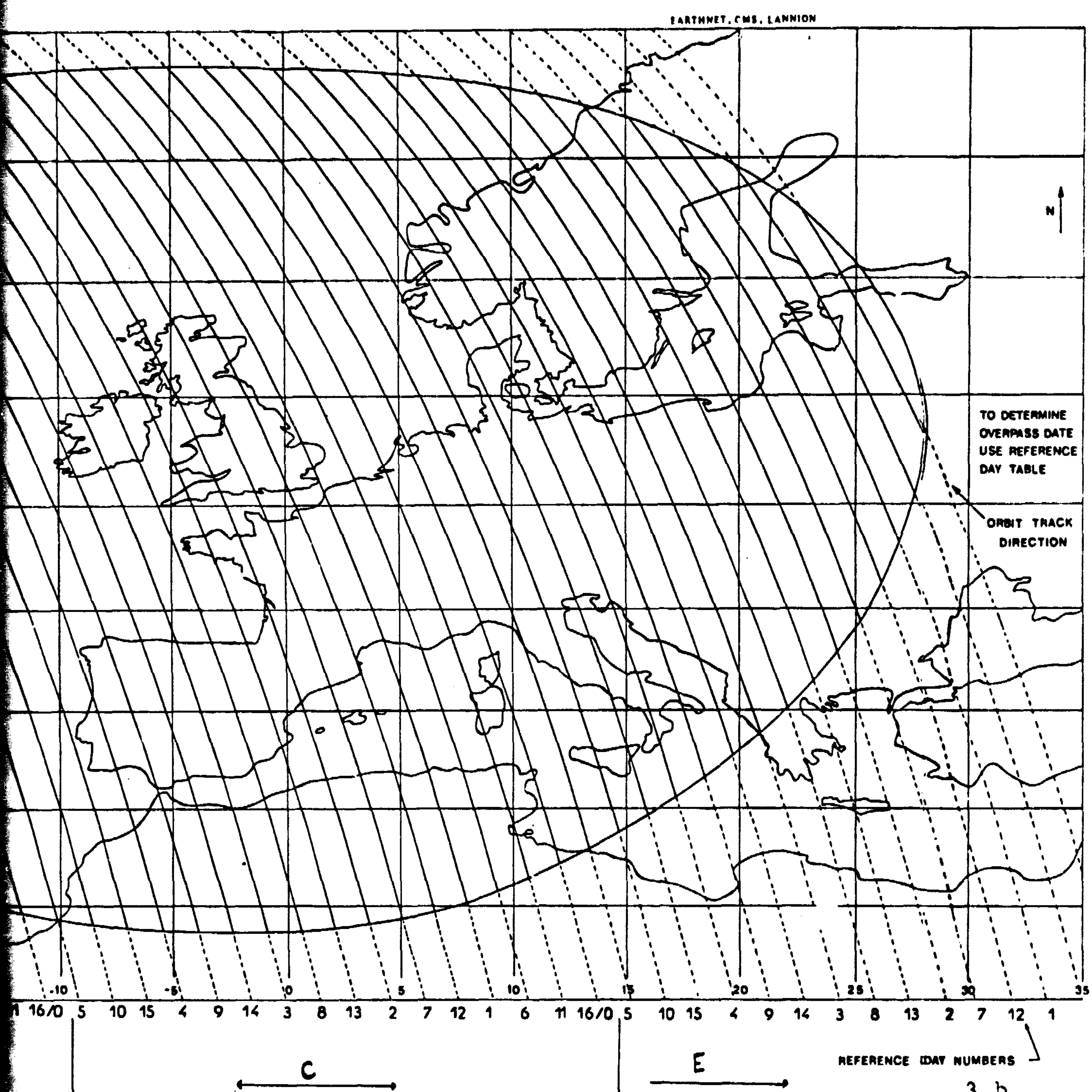
W

C

13

QUALITY

PPING MISSION (HCMM) COVERAGE EUROPE DAY

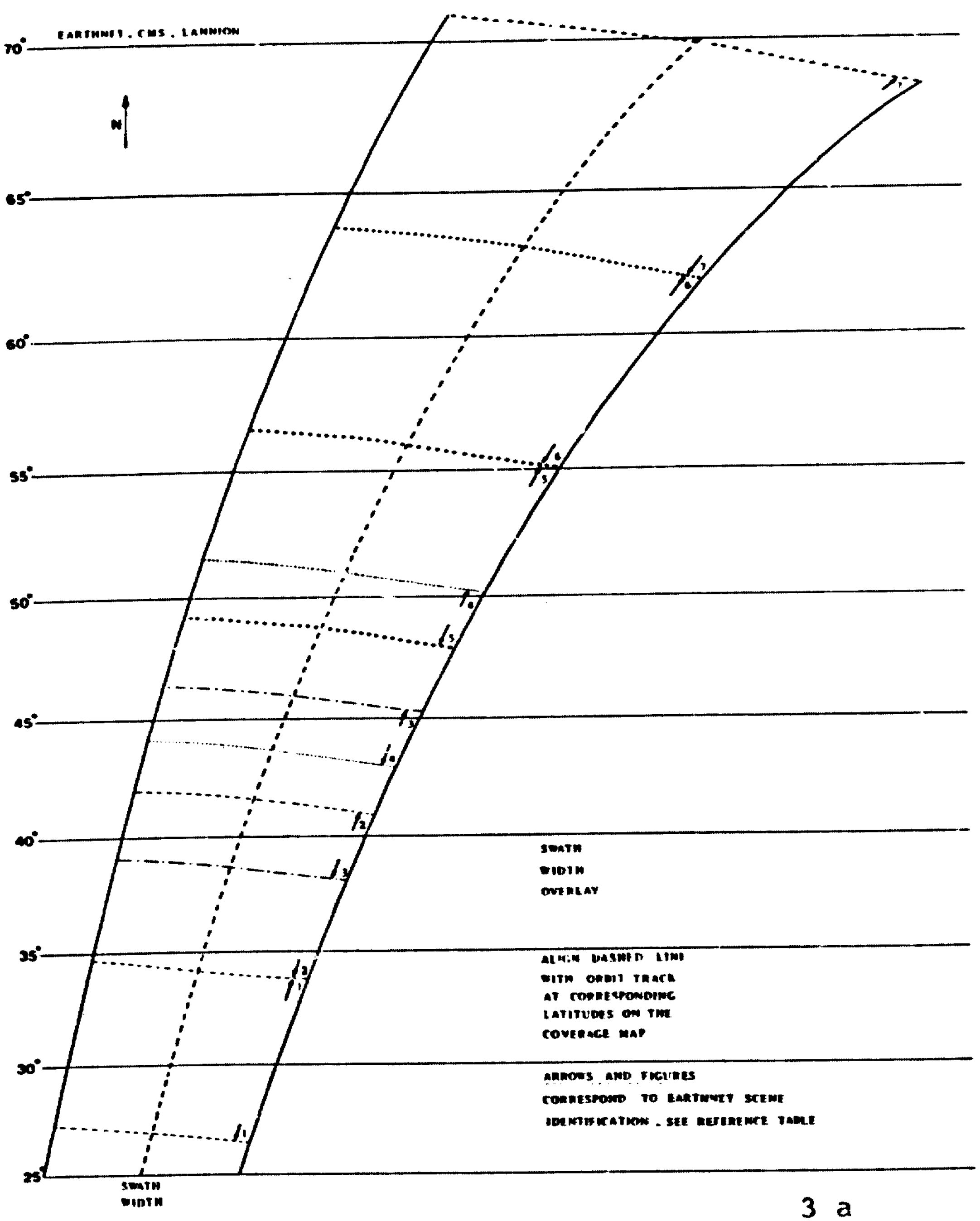


3 b

FOLDOUT FRAME

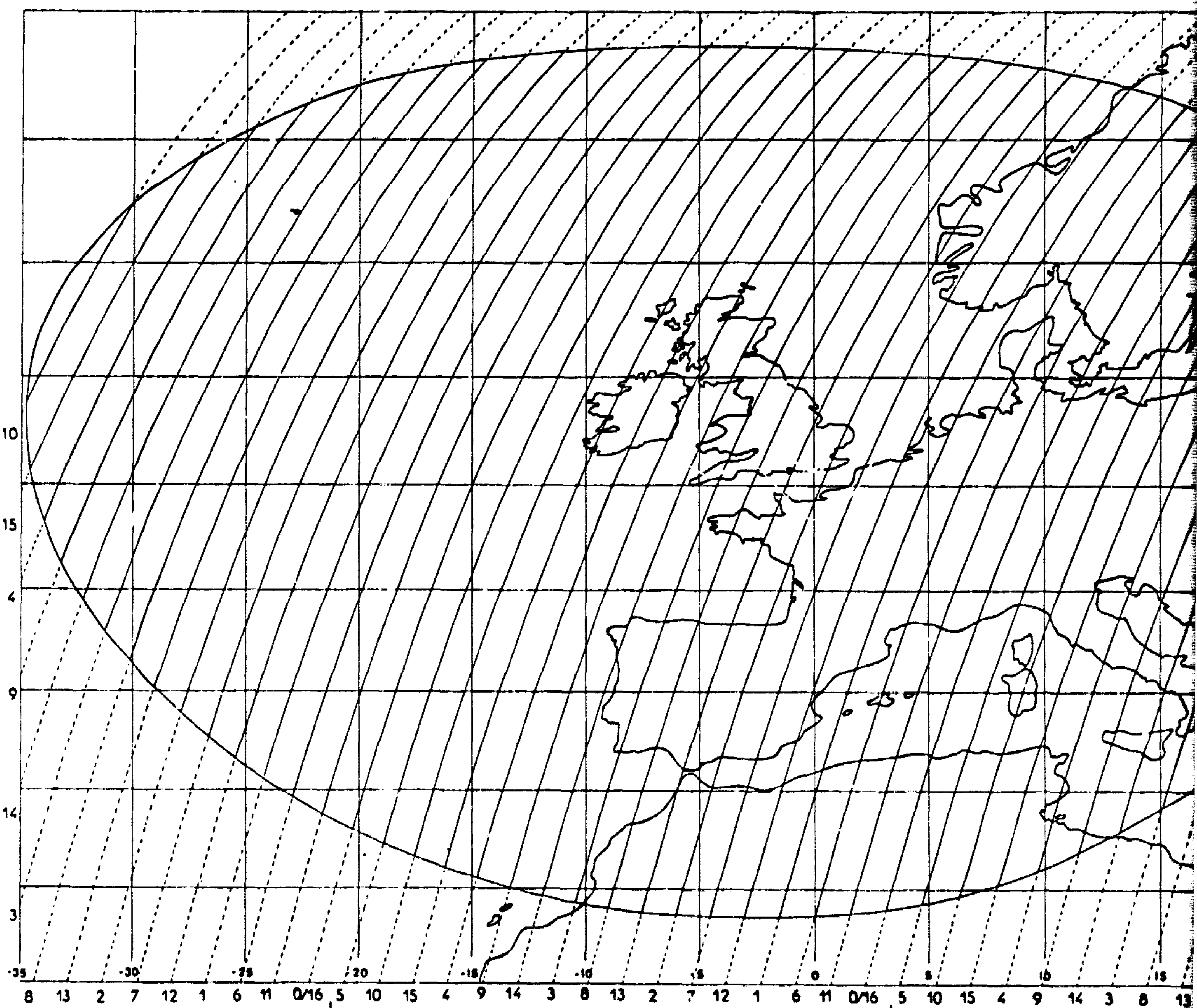
QUALITY

HCMM COVERAGE EUROPE NIGHT



3 a

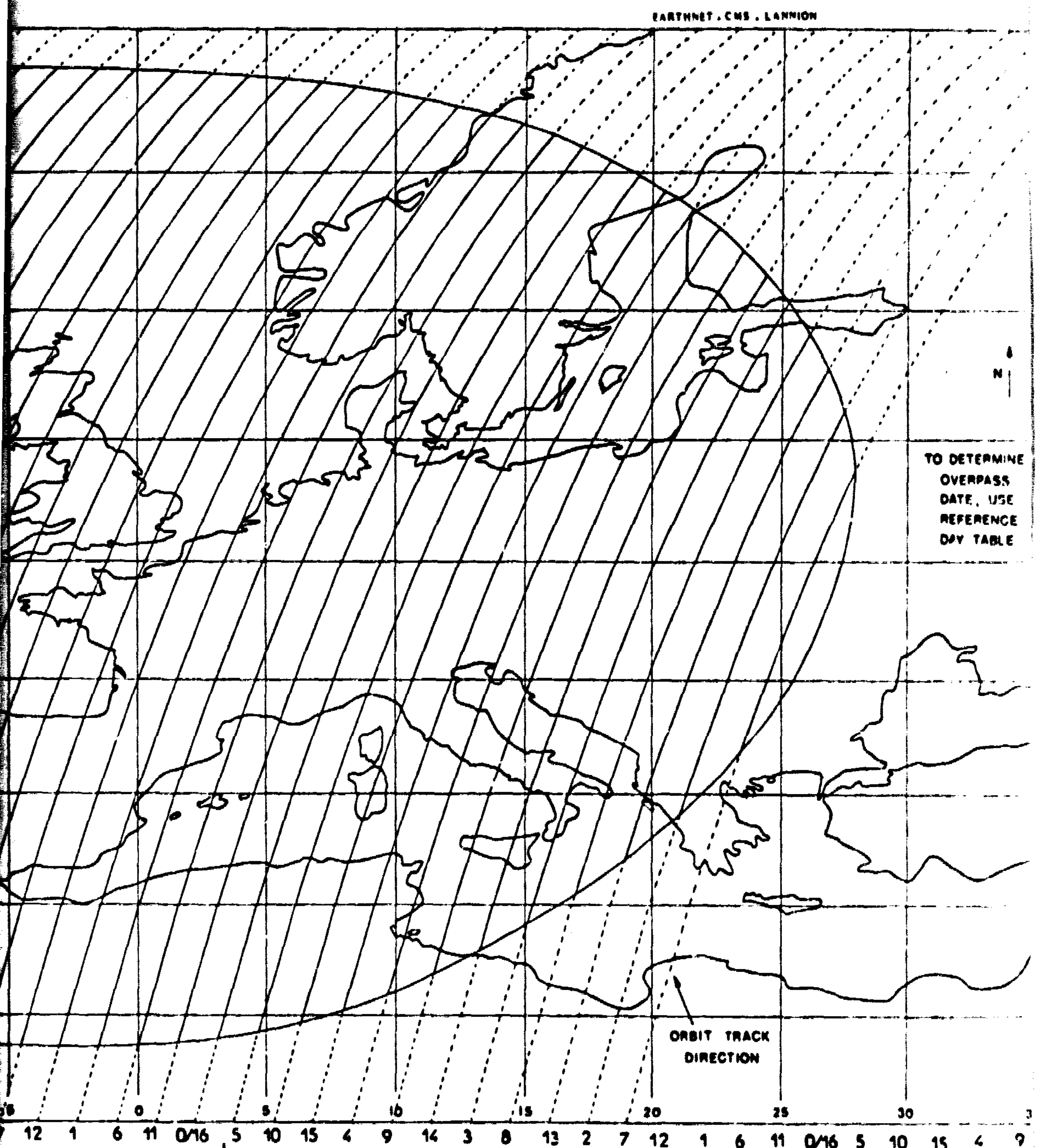
HEAT CAPACITY MAPPING MISSION (HCMM) COVERAGE EUROPE NIGHT



W | C FOLDOUT FRAME | E

QUALITY

CMM) COVERAGE EUROPE NIGHT



OUT FRAME | E

FOLDOUT FRAME

3 a

QUALITY

ESA / EARTHNET DATA DISTRIBUTION SCHEME.
STANDARD ORDERS (QUICK-LOOKS) AND
RETROSPECTIVE ORDERS (R.O.)

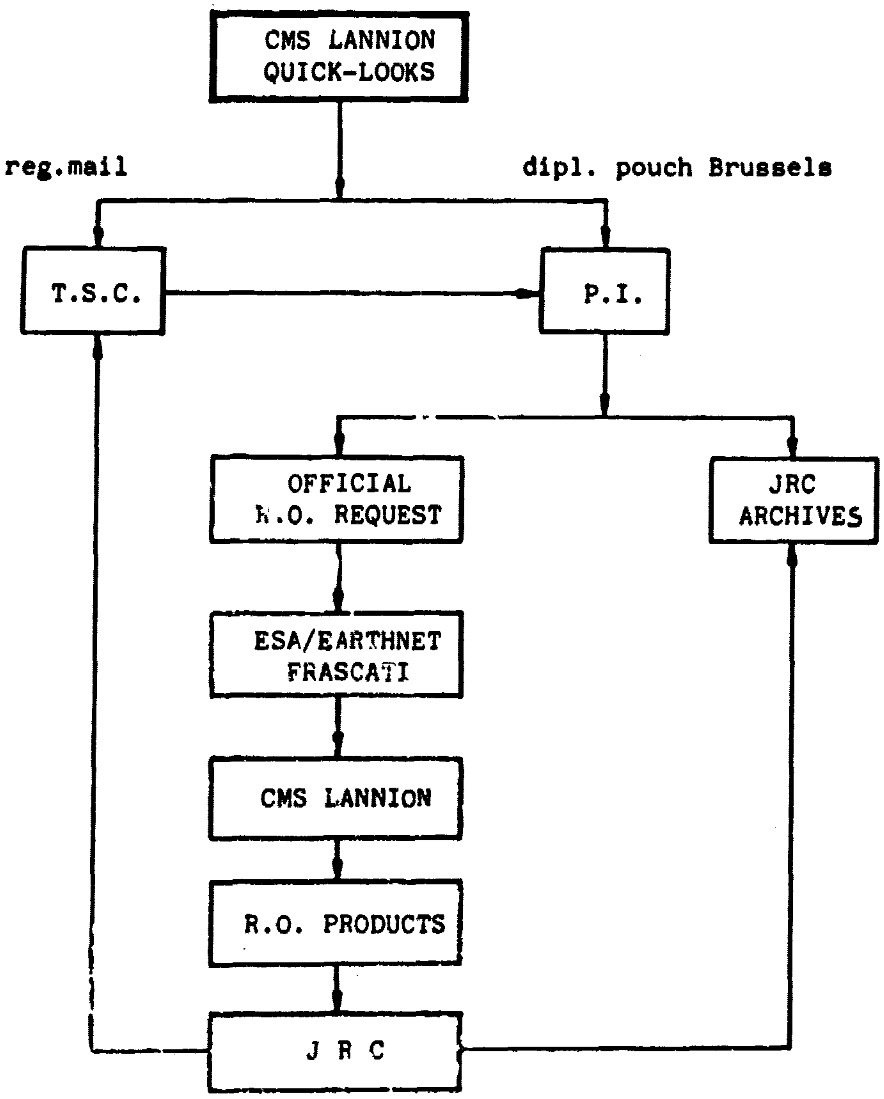


Fig. 2

In Tab. 5 the overall situation of RO is resumed as far as NASA/GSFC and ESA/EARTHNET CCTs production are concerned. The distribution by national Test-site Groups is also indicated.

TABLE V

R.O. SCENES ON CCT's

	NASA	ESA	TOTAL
Ordered	81	47	128
Received	46	8	54
Still not Received	35	39	74

Germany:	64
Italy:	12
Benelux:	21
France:	21
United Kingdom:	11

4.1. Evaporation and Soil Moisture

4.1.1. Bare soil

4.1.1.1. The TELL-US model (JRC)

Tests of the TELL-US model reported in the 1st PR had shown the sensitivity of the model to the value of the soil heat capacity used in the calculations (TELLUS NEWSLETTER 8). Originally, an extremely high value of the soil heat capacity had been employed in all cases, permitting a speedy calculation with time steps of one hour. The explicit difference scheme of Du Fort and Frankel used in the model required time steps as small as 36 seconds for realistic values of the soil heat capacity, increasing computer time considerably.

In order to correct this situation, the explicite difference scheme for the numerical approximation of the ground heat flux was replaced by an implicite finite difference method. This method is extremely stable and permits the combination of realistic values of the soil heat capacity with long time steps.
The programming aspects of the method and examples of the results obtained are described in TELLUS NEWSLETTER 11 (Annex 1).

4.1.1.2. Analytical model (ULP/GRTR)

A simple one-dimensional analytical model of the thermal behaviour of soils has been developed (HECHINGER, 1979). The model serves as a basis for a rapid inversion procedure permitting, on a pixel by pixel basis, the calculation of ground properties from remotely sensed temperatures. The model is based on the Fourier analysis of the various fluxes involved while accepting the following approximations:

- Linearization of the thermal radiation
- Use of the mean of the transfer coefficient for sensible and latent heat transfer, resp.

- Linearization of the difference in the partial water vapour pressure between the air and the soil surface.

The model gave a reasonable agreement with results calculated by the TERGRA model. A sensitivity analysis gave similar results as those obtained by Rosema (ROSEMA, 1978). The inversion procedure will now be applied to satellite data.

4.1.2. Soil covered by vegetation

4.1.2.1. Adaptation of the TELL-US model to surfaces covered by vegetation (JRC)

The TELL-US model had been set up for the evaluation of soil moisture and evaporation of a bare or scarcely vegetated surfaces from the daily maximum and minimum surface temperature. The use of two temperatures permitted both the soil thermal inertia and surface relative humidity to be calculated by the model, one being related to the bulk moisture content of the top soil layer, the other to the moisture content of the soil surface and as such to evaporation.

The situation is different for a soil covered by a dense vegetation. In this case, the contribution of the soil heat flux to the energy balance at the surface is small during the day, and both the relative humidity at the surface of the vegetation and its thermal inertia are functions of the bulk moisture content of the root zone. Therefore, there is no need to distinguish between these two variables and the use of the night-time minimum surface temperature becomes superfluous.

Accordingly, a Simplified Evaporation Algorithm (SEAL) has been developed by introducing the following changes into the TELL-US model:

The simulation period is reduced to the time between sunrise and sunset.
The ground heat flux is assumed to be 10% of the net radiation.

The course of the daily surface temperature is calculated for different but constant values of bulk stomatal resistance, instead of surface relative humidity and thermal inertia.

For a certain stomatal resistance there will be agreement between the remotely sensed surface temperature close to the daily maximum and the simulated crop surface temperature at that time. The stomatal resistance thus obtained permits the calculation of the daily evapotranspiration.

A first result obtained by the algorithm agreed to within 5% with the daily evapotranspiration calculated by the TERGRA model, but further tests with experimental field data will still have to be carried out.

A more detailed description of the algorithm and of the first test results is given in TELLUS NEWSLETTER 11 (Annex 1).

4.1.2.2. Operational model based on the evaluation of the net radiation from remotely sensed data (JRC)

This operational model (TELOP) is based on a correlation between cumulative evapotranspiration, net radiation and soil moisture in the root zone weighted for root density. The slope of the linear function relating cumulative ET to net radiation changes at a "critical" value of soil moisture.

Using albedo data from the literature, net radiation is calculated from reflected solar radiation and surface temperature measured by remote sensing methods, and from incoming long wave radiation derived by Swinbank's formula.

A relation between net radiation and evapotranspiration has to be established experimentally for the soil and the crop in order to permit the calculation of ET.

The method was developed and tested on data from grassland collected during the Policoro Measurement Campaign 1978 in the South of Italy. For a 10-day period, cumulative ET calculated by TELOP agreed to within 10% with values from the TERGRA model.

Details of the method and of the experimental procedure are given in Annex 7 (GREGOIRE, 1980).

4.1.3. Field operations

In addition to testing the algorithms for the interpretation of HCMM and aircraft data, field operations carried out in the post-launch phase had the purpose of obtaining ground and aircraft data simultaneous with the passage of the HCMM satellite. In this way, problems posed by the heterogeneity of the surface, the calibration of the HCMR and the effect of the atmosphere should be able to be, at least partially, solved. Field operations were of two kinds:

- Flight experiments involving both airborne and ground based measurements of a duration of days
- Continuous field measurements lasting a number of weeks or even months.

4.1.3.1. Flight experiments

From flight experiments took place in the post-launch period, in the Netherlands, the United Kingdom, Italy and the Federal Republic of Germany. The Dutch and the British flights were organized by National Institutes, the Italian and German flights were Joint Flight Experiments (JFE) with the participation of both National Institutes and the Joint Research Centre. In addition, further results of the JFE France 1977 are presented in this section.

4.1.3.1.1. The Netherlands (ICW)

A flight with an airborne MSS having 10 channels between 0.38 and 1.1 /um and a 4-channel SAT thermal scanner was carried out on July 31,1978 over the peat area of Dreuthe (53°6' N, 6°40' E). Flight time coincided with that of satellite scene AA0096:1226.0.1, 2.

The flight strip included sub-irrigated and non-irrigated cropland (potatoes) as well as heath.

Unfortunately, due to technical difficulties of the GDTA/ SAT thermal scanner, valid data could be obtained only from a small part of the flight strip. This incident made an accurate comparison of aircraft and satellite measured surface temperatures impossible.

4.1.3.1.2. United Kingdom (IHW, UL/DG, UR/DG)

After the JFE campaign made in the pre-launch period (see 1st PR, p. 32 second flight was carried out over the Grendon-Underwood Experimental Catchment (51° 53' N, 1°W) on September 29-30, 1979. A Fairey two-channel thermal scanner (3÷5.5 /um and 9÷11 /um) was flown over an 8-km strip at altitudes of 750 and 3000 m.

The day pass was on Sept. 29 13.00 GMT, the night pass on Sept. 30 02.00 GMT.

The flight strip consisted of grassland and large areas of bare soil. Seven permanent measuring fields are established in the area since 1978.
At all of these sites soil temperature and the max. and min. air temperature are read daily. Most of the sites contain neutron access tubes for measuring soil moisture. Additional micrometeorological instrumentation was installed for the flight.

Soil and plant surface temperatures were measured with portable radiometers and additional soil moisture samples were taken. A lake 1 x 0.5 km served for the calibration of the thermal scanner data.

Without atmospheric corrections and for the day flight there was good agreement between the temperatures measured from 750 m and on the ground, while those measured from 3000 m were lower by about 2°C.
During the night flight ground frost had developed and the temperatures of land surfaces measured from 3000 m were higher by about 2.5°C than those measured from 750 m. No differences were noted in the lake temperature.

The full evaluation of the data including atmospheric corrections is still in progress. No satellite cover is available by NASA for the flight dates.

4.1.3.1.3. Italy. (CSATA, UBA/IACE, UBA/IF, UFI/IAGCE, UCEA, JRC and others)

In the framework of the JFE programme launched by the JRC, a series of flights were carried out in Southern Italy (at Sibari 1) during the month of July 1978 (15%30).

- To obtain experimental data, both airborne and on the ground, to test models for the evaluation of evapotranspiration and moisture of soils covered by vegetation and bare (thermal inertia) and to compare these with HCMM satellite data.
- To study scale effects and atmospheric corrections by flights at various altitudes.

JRC provided the organization, coordination, experimental team and most part of the ground instrumentation for the flight campaign. The following Italian co-investigators participated with staff and instruments:

- Istituto di Agronomia, Università di Bari
  Centro Studi Applicazioni Tecnologie Avanzate, Bari
  Ufficio Centrale Ecologia Agraria, Roma
  Laboratorio Radioecofisiologia Vegetale, Roma joined the Italian team. His contribution was relevant to micrometeorologic measurements.
  Istituto di Agronomia Generale, Università Firenze
  Istituto di Fisica, Università di Bari.

The ground staff involved about 40 people.

<u>The flights</u>

The flights were performed by DFVLR (Germany) with a DORNIER aircraft equipped with Bendix Multispectral Scanner (MSS), PRT-5 infrared radiometer, RMK false colour camera, Hasselblad camera.

Four test fields were completely instrumented with micro-meteorological and soil detectors: two bare soil fields (dry and irrigated) and two sugarbeet fields at different soil moisture.

Numerous soil samples were taken for the determination of the various soil parameters involved in the models.

The flights were performed at several altitudes to study atmospheric effects and one out of the test field axis for edge effects evaluation.

A 10 x 10 m panel of known emissivity (IR) and reflectivity (VIS and NIR) was built on the field and continuously monitored during the flight in order to check the MSS output.

The campaign may be considered successful as preliminary data, quicklook and false-colour photographs are indicating. JRC has received aircraft CCTs.

Data interpretation

Spoiling of data has begun at JRC, Ispra and at CSATA, Bari. It appears that data collected on the test areas are satisfactory and that their processing can be carried out. Standardization of data by CSATA, Bari is in progress. Data processing and interpretation is going to start in collaboration between Italian Institutes (CSATA, University of Bari) and JRC. Laboratory analysis of soil samples being concluded by the Agronomy Institute, Univ. Bari.

Due to the failure of the video colour display, the data processing could be started only in 1980. In any case series of look-up tables have been generated to determine thermal inertia, soil moisture and cumulated evaporation. Conclusive results are expected by end 1980.

4.1.3.1.4. Germany

European Joint Measuring Campaign 1979 (UG/IBW, UL/IG, UR/~G, IHW, JRC and others)

During the WG-2 meeting at Wageningen of November 28-29, 1978 a JRC proposal was accepted for a European Joint Measuring Campaign on a test-area large and homogeneous enough to match HCMM resolution.

The experiment was carried out on the period 3-27 June 1979 on a 5x4 km area (a. 50 HCMM pixels) of the test site No.15 (West Germany) with the participation of field-teams of JRC and of many European countries.

Choice of the test-area and campaign organization requested a considerable effort by the JRC staff and Coinvestigators. Experimental common procedures were settled up together with tender for aircraft flights.
Data collection, processing and interpretation are coordinated by the JRC. Ispra's Computing Centre is well advanced in preparing the software for geometric and atmospheric corrections and model applications.

Ground measurements and multi spectral scanner flights were performed simultaneously with at least one night/day series of satellite overpasses.

Aim of the experiment:

- To obtain experimental data, both airborne and on ground, in order to test existing evapotranspiration and soil moisture models for the HCMM experiment (underflight experiment)
- To perform eventually some scale effect studies.

Main characteristics of the campaign:

- location: near Pattensen, South of Hannover (52° 15'N, 9° 48'E)
- flat area about 25 km^2 of very homogeneous loess (2÷3 m thick) with very sparse trees
- experimental fields dimension: 10 ha. or more
- water table: 2-3 m deep
- 9 measuring ground stations: 2 on wheat, 2 on barley, 2 on sunbar beet, bare soil, water pond, Steinhuder lake

- flight performed by Spacetec-Hansa Luftbild with a Air-commander, twin motor aircraft equipped with a 11 channels Daedalus MSS (VIS + NIR + TIR) and a RMK false colour camera
- successive flights altitude: 600, 1000 and 3000 m.

Participation

The following Coinvestigators participated with staff and instruments:

- JRC Ispra
  - Flight organization and micrometeorological measurements on bare soils
- Institute für Bodenkunde und Waldernährung der Universität Göttingen (Germany)
  - Crop and soil characteristics for the tested sites
- Deutscher Wetterdienst-Zentrale Agrarmeteorologische Forschungsstelle (Germany)
  - Agrobiometeorological measurements over barley and sugar beets
- Institut für Meteorologie und Klimatologie der Universität, Hannover (Germany)
  - Calibration of the IR/MSS channel on a water pond; wind velocity, air, temperature and humidity profiles up to 45 m, in collection with Wetteramt, Hannover
  - wheather forecasting and radiosonde observation of cloud also during the stand-by period
  - water temperature of Steinhuder lake for comparison with satellite data
- Department of Geography, University of Leeds and Department of Geography, University of Reading (U.K.)
  - Micrometeorological and soil measurements on wheat, barley and sugar beets

. Institute of Hydrology, Wallingford (U.K.)

- Sensible heat flux, micrometeorological and surface emissivity measurements on wheat, barley and sugar beets.

Results

Experimental data collection completed. Data have been centralized at JRC, pre-processed, filed and distributed. Data processing and interpretation are in progress.
First results are expected in the second half of 1980.

4.1.3.1.5. France (INRA/ST, INRA/SB)

Data obtained during the Joint Flight Experiment, France on September 30, 1977 in the region of Voves, South of Chartres (48° 13' 42" N, 1° 36' 01" E) have been further evaluated.

The data analysed came from an area of 2.7 x 6.5 km represented by 160,000 pixels and it covers with 70 individual fields about 56% of the total scene. Corn covered 25% of the surface, sugar beets 2%, rape 2%, forest 1%, bare soil 22%, stubble 4%.

Only two group of surfaces could be distinguished by their surface temperatures, soils covered by vegetation (corn, sugar-beet, forest) and bare soil (ploughed soil, stubble). This differenciation became more pronounced when the day-night temperature difference was used.

The temperature distribution in the corn fields was investigated in greater detail. The variability of the surface temperature was found to be slightly larger inside the individual fields than between the various fields. Therefore, for a given site the mean surface temperature of one crop type may serve for the calculation of evapotranspiration instead of a calculation for each individual field or pixel by pixel.

For the conditions of the flight, the evaporation from three types of surfaces has been calculated as a function of surface temperature. For corn, a difference in surface temperature of 1°C was equivalent to a latent heat flux of 100 Wm^{-2} i.e. an evapotranspiration of about 1 mm/day. The effect was only 50 Wm^{-2} for sugar beets and 25 Wm^{-2} for stubble.

Taking into account the standard deviation of the temperature in a corn field, for the conditions of the flight, the ET of such could be calculated with an accuracy of $\pm$ 90 Wm^{-2}. The details of the analysis are presented in TELLUS NEWSLETTER 13 (Annex 3).

4.1.3.2. Continuous field measurements

These measurements campaigns are being carried out to obtain data sets over long time periods permitting a comparison of statistical validity between ground measured evaporation and soil moisture and values derived from R.S. data. These experiments should be considered complementary to the JF 'S ones.

4.1.3.2.1. Italy

Policoro Campaign 1978 (CSATA, UBA/IAGCE, JRC)

As it is well known the evaluation of evapotranspiration (ET) is very useful for a rational management of the water resources and agricultural crops especially if they are limited and ET can be measured continuously on large regions.

Various methodology have been developed and applied to the evaluation of ET, but they require normally a rather complex instrumentation not suitable for systematic and synoptical measurements. Remote sensing techniques to fit better all these difficulties.

This is the reason why JRC-Ispra decided to realize a measuring campaign to test evapotranspiration and soil moisture models (TERGRA and TELL-US written for R.S. techniques for grass and other crops in semiarid conditions.

The models require the measurement of parameters into the soil, within the air boundary layer and remote radiometry of the surface (VIS, NIR and TIR).

The campaign was made in collaboration between the JRC Ispra (organization, acquisition and processing of data), CSATA, Bari and the Agronomy Institute of Bari University (soil measurements and data interpretation).

As a suitable test area was chosen an experimental farm (about 50 ha) belonging to the Agronomy Institute of Bari University, well equipped with two drainage lysimeters, a continuous recording evaporation pan, wind speed, air humidity and ground temperature recorders, and irrigation system. It is situated in South Italy near Policoro (40° 13'N; 16° 40' E) on the Ionian Sea coast.
The test area (a grass field of 60 m x 60 m) was divided into two parts submitted to different irrigation conditions corresponding to variable humidity conditions and crop stress.

The following parameters were measured:

- net radiation
- solar radiation
- albedo
- incident long-wave radiation (sky radiation)
- VIS-NIR and IR radiation
- soil temperature (at four depths)
- heat flux into the soil (at two depths)
- soil parameters
- soil humidity (tensiometers and drilling)
- dry and wet bulb temperatures (Bowen ratio)
- wind velocity and direction
- pressure.

In order to have the field surface free, all cables were brought to the measurement station (data logger and magnetic recorder) via plastic tubing buried into the ground. The VIS-NIR and IR radiometers were put at 5 m above the field by using a specially designed support. This allowed to take measurements on a spot of sufficient size.

Two panels (one for the IR and one for the VIS-NIR) were used once every two days to provide a check and calibrating outputs for the radiometers.

Two collaborators from CSATA , Bari had the task to staff the test area, maintain the equipments, unload and load the magnetic recorder, send the tapes to Bari, where they were read and processed.

JRC's data acquisition system proved to be highly reliable (only some percents of data have been lost owing to local electrical mains failure).

The campaign lasted 27 days, from June 23 to July 20,1978; finally, data collected during 21 days resulted satisfactory.

Preliminary results on this campaign were presented at the TELLUS Working Group-2, Rome on November 20-21, 1979. The final report will appear in the next few months. It can be anticipated that this campaign was successfully carried out and does form the data base for further developments of simulation models and/or simplified regression approaches. The conclusion is that the TERGRA model estimates quite well actual ET (agreement within 15% with values calculated by two indipendent methods, Bowen ratio and Penman equation, and net radiation) but overestimates crop temperatures during the daytime and underestimates them during nightime. In any case, it requires a large amount of ground input data measured for the whole period of simulation.

Using the data set from the Policoro campaign 1978 a regression model is being developed at JRC Ispra. This model is based on remotely sensed crop temperature and ground measurements of air temperature and soil humidity at 13.00 hours. It worked properly over a period of 7 days giving evapotranspiration and soil humidity as compared with TERGRA and experimental data.

The data processing requested a sensitivity analysis of TERGRA and TELL-US models which has been performed by CSATA.

4.1.3.2.2. France (INRA/CRASE/SE)

Continuous measurements of the energy balance and of the radiometric surface temperature have been carried out in the period 1978-80 on the test site of the Crau in Southern France (43° 50' N, 4° 56' E).

The site, on flat land, consists of a large area of irrigated pasture (about 200 ha) and about 30 ha of dryland alfalfa surrounded by about 100 km^2 of non-irrigated grassland. Two identical monitoring stations were established, one in the irrigated and the other in the dry zone. The following parameters were measured in each station every 10 minutes:

- Net radiation
- Soil heat flux
- Wet and dry bulb temperature of the air at 0.3
- and 2 m
- Surface temperature (HEIMANN KT-24)
- Windspeed at 2 m
- Soil temperature at 0.1, 0.5 m depth.

Global radiation was measured at Montfavet (40 km from the site).

The measurements covered the period July-October 1978 and April 1979 - March 1980.

Evapotranspiration was calculated for both the dry and irrigated zone by four methods which were compared with the energy balance method serving as a reference.

Two of the four methods did not involve the surface temperature. They were the approximations ET_{Rn} = Rn (HLAVEK et al, 1974), liable to be valid under wet conditions.

and $ET_{eq} = (\Delta/\Delta+\gamma)Rn$ i.e. the first term of Penman's equation, adapted to moderately dry conditions (PERRIER, 1977).

The methods using surface temperature were the combined energy balance-aerodynamic approach (ET_{TS}) and a simplified approach (ET_{JT}), proposed by Jackson et al. (1977).

The tests showed the two surface temperature methods to give relatively satisfactory results both in the dry and wet zone, with a precision of 10-15% compared with the reference method. As was to be expected, ET_{eq} gave satisfactory results only in the dry zone and ET_{Rn} in the irrigated zone.

Although thermography increased the precision in the estimate of ET relative to the most suitable "classical" method by only 5-8%, its great advantage lies in its equal suitability for both dry and wet conditions. The use of the ET_{JT} method was found to be especially attractive as it does not require extensive ground measurements and the evaluation of the surface roughness.

A detailed description of the results is presented in TELLUS NEWSLETTER 16 (Annex 6).

4.1.4. Interpretation of satellite data

The first applications of satellite thermal data to the evaluation of ET were made in the Netherlands and in France. In the Netherlands it was attempted to map groundwater levels with the aid of HCMM thermal data. Only a few suitable data products were available for this text site, which poses particular problems due to its climatology and land use pattern.

On the French test area of the Crau (TS No. 4) thermal data from NOAA-5 and of HCMM have been compared for the dry and irrigated plots of the site.

4.1.4.1. The Netherlands (EARS)

The mapping of groundwater levels was carried out in view of creating maps of the potential natural vegetation of parts of the Netherlands.

It was based on the assumption that evaporation from a crop surface or bare soil depended, among others, on the supply rate of groundwater to the root zone or the soil surface, and as such on the groundwater level.

The approach consisted of mapping the evapotranspiration of a region with the aid of the TELL-US model and comparing this map with a conventional map of the groundwater level. The land use was derived from vegetation maps or from topographic maps 1 : 50,000.

The investigation centered on the following regions of the Netherlands:

North Holland (52° 45' N, 4° 50' E)
South Flevoland (52° 25' N, 5° 30' E)
Gelderse Valley (52° N, 6° E).

<u>HCMM scenes used.</u> The following HCMM scenes were used either in photographic form combined with densitometry or as computer print outs of CCT's:

30.5.78	AA0034.0212.0.3	CCT, film
03.6.78	AA0038.1247.0.1,2	film
19.6.78	AA0054.1247.0.1,2	film
20.6.78	AA0055.0203.0.3	film
	AA0055.1304.0.1,2	film
17.7.78	AA0082.1305.0.1,2	CCT, film

At the time this study was undertaken the one consecutive D/N/D scene was only available on film.

Calculation of the surface temperature. A number of problems had to be solved to derive the effective surface temperature from HCMM data:

- Atmospheric corrections: The thermal data of July 17, 1978 we corrected for the effect of the atmosphere by the RADTRA model. Radiosonde data from the KNMI at De Bilt served as input to the model. The correction ranged from 0°C to 7°C for a measured surface temperature of 7° and 35°C, resp..

- Emissivity: Emissivity corrections were applied according to values found in the literature and the land use. A change in the emission coefficient of 1% leads for grassland, under the conditions studied, to a change of ET of 10%.

- Mixed pixels: On this test site, pixels are in many cases not uniformly occupied by one land-use class. The temperature as measured by the satellite is a mean temperature of the pixel (T_o), while the surface temperature of the major land use class of the pixel (T_1) may be different, according to the fraction of the surface occupied (O_2) and the temperature of the secondary land use class of the pixel (T_2).

The following relation was employed to calculate the surface temperature of the major land use type of mixed pixels:

$$T_1 = \frac{T_o - T_2 O_2}{1 - O_2}$$

The surface temperature of the secondary land use class was estimated from surfaces where it occupied a number of pixels. As an example, the surface temperature of the water in drainage ditches was assumed to be equal to the temperature of nearly lakes.

The influence of mixed pixels on the calculation of evapotranspiration may be considerable. The neglect of 10% of heath in a surface of potentially transpiring forest will reduce ET as calculated from surface temperature by 66%. The neglect of the same percentage of water surface (drainage ditches) on grassland will overestimate evapotranspiration by 11%.

- Advection: A distinct trend of the surface temperature as a function of the distance from the coast was noted. It was observed on all agricultural surfaces and independent of the depth of the groundwater, but followed the predominant wind direction.

At night (May 30, 1978) a logarithmic increase of 3°C of the surface temperature over a distance of 20 km from the coast was noted. Due to this effect, the image was not used for mapping of the TI.

During the day (July 17, 1978) the surface temperature of grassland in North Holland increased linearly by about 5°C at a distance of 20 km downwind from the coast. The effective surface temperatures were corrected for this trend.

Relation between surface temperature and groundwater level.

- Relation due to factors other than ET: For North Holland, the following relation between the surface temperature on June 3 (AA0038.1247.0.2) and the groundwater level could be found:

Depth to groundwater, m	Mean surface temperature, corrected for regional trend, K°
<0.5	300
0.5 - 0.8	304
0.8 - 1.2	306
<1.2	313

This relation needs the following explanation : areas with a groundwater level of less than 0.8 m are mostly grassland, cut up by open drainage ditches. Especially at groundwater levels of less than 0.5 m these ditches take up a considerable fraction (30%) of the surface and the low temperature of this area seems to be due to the presence of open water surfaces, the temperature of which were 15°-20° below that of grassland.

The higher surface temperatures of areas with groundwater levels deeper than 0.8 m are to a large part due to the presence of bare soil, and of sand dunes in areas with groundwater deeper than 1.2 m.

- Relation due to ET. The relation depth of groundwater-evapotranspiration as calculated from surface temperature was investigated for grassland on July 17. The results are summarized in the following table:

Table 6

Depth to groundwater, m	ET/ETP		
	North Holland	Betuwe	Gelderse Vallei
<0.5	0. 91	0.83	-
0.5 - 0.8	0. 90	(0.92)*	0. 91
0.8 - 1.2	0. 92	0. 82	0. 89
<1.2	-	0. 83	0. 83

*) Value probably due to incorrect evaluation of secondary land use class.

The soil type was clay and clay on peat in North Holland and the Betuwe and a sandy soil in the Gelderse Valley.

An effect of a lowering of the groundwater level on evapotranspiration could only be noted for the sandy soil of the Gelderse Valley. There was no effect on the heavier clay soils, at least not for the rather net conditions of summer 1978. Details of the investigation are reported in Annex 8 .

4.1.4.2. France (INRA/CRASE/SE)

While waiting for sufficient HCMM images over the Crau test site to become available, the surface temperature of the zone measured by the NOAA-5 satellite was investigated. Three irrigated and one dry zone have been defined on the NOAA-5 images, with about 200 pixels in the dry and the same number in the irrigated area.

During the summer months of 1978 the apparent surface temperature of the dry zone was consistently higher than that of the irrigated zone, this difference reaching up to 10°C.

Without atmospheric corrections surfaces temperatures from NOAA and ground measured temperatures differed by 4-5°C. For high surface temperatures, satellite temperatures were lower (atmospheric effect), for low surface temperatures higher (mixed pixel effect) than ground measured temperatures.

For the scene AA0082.1303.0.1,2 (17.7.78) a comparison with the NOAA-5 image of the same day 08.35 GMT was carried out. The results are given in the table below:

Table 6

Zone	Temperatures, °C			
	NOAA-5	HCMM	GROUND	AIR
Dry,	39	33	50	33
Wet	34	24	40	31

No atmospheric corrections were applied, but in any case HCMM measured temperatures were lower by 6-10°C or even more than NOAA-5 temperatures, as the surface heated up in the 4½ hours separating the passage of the two satellites.

The treatment of the NOAA-5 data was carried out by CTAMN-Ecole des Mines, Sophia-Antipolis while the HCMM image was analysed by INRA/ST.

4.2. Heat Budget

4.2.1. Natural phenomena

This part of the investigation concerns mesoscale heat budgets not particularly affected by man-made heat release. It consists in particular in a study of the relation between different land use pattern and surface temperature as well as the relation between topography and surface temperature.

4.2.1.1. Superposition of HCMM thermal data on other satellite imagery and thematic maps (UF/GI)

As a first step in interpreting HCMM thermal data a system was worked out and tested permitting the superposition of this data in digital form on other sources of information e.g. images from LANDSAT, digitized maps. The system permits to create a multi-channel data structure for the region under investigation, channels being one or more HCMM data sets (multitemporal analysis) and thematic information (land use, topography).
The development of the system and image processing was carried out at DFVLR, Institut für Nachrichtentechnik, Oberpfaffenhoven, FRG.

HCMM scene used: May 30, 1978 AA0034.0213.0.3

Though only one HCMM scene was available this was sufficient for setting up the data structure which can now easily be applied to new HCMM images as they become available.

Area under investigation: the area investigated covers the Upper Rhine Valley between Basel (47° 33' N, 70° 36' E) and Frankfurt (50° 7' N, 8° 36' E).

Both sides of the Rhine river are exemplified by a variety of landscape types: the holocene flood plain with residual forests; the intensily cultivated quaternary accumulation plain, interspersed in some places with forested sand and gravel terrain; the orchards and vineyards of the foothill zone; the strongly dissected forested ascent to the mountainous flanks of the Graben; forested plateaus, extending away from the Upper Rhine Valley and divided by large valleys, and which on the side away from the Rhine are bounded by a wellmarked rock formation and thereafter replaced by a relatively unforested farm landscape.

On the Upper Rhine Valley there are several very densely populated regions, like Frankfurt and Mannheim-Ludwigshafen in the Federal Republic of Germany, Strasbourg in France, and Basel in Switzerland. Outside of these centres with their great need for space, a strong industrial development is taking place, especially along the Rhine river on the German and even more so on the French side, a development which in this area has led to an active discussion about the possibilities of a man-made modification of the regional heat-budget.

Data base: The following maps, given in Table 7 , have served as data base for this study:

Table 7

Contents	Type	Scale	Source
Relief	contour map	1:2,000,000	Hydrologischer Atlas der FRG
Forest distribution	binary mosaic map	1:2,000,000	Hydrologischer Atlas der FRG
Urban , built-up areas	binary mosaic map	1:1,000,000	FRG in Karten
Water	network of linear elements	1:2,000,000	Hydrologischer Atlas der FRG

Overview of the thematic maps which have been digitized and with which thermal images have been superimposed.

In addition, two LANDSAT scenes of Aug. 9, 1975 and Aug. 28, 1975 were employed. These scenes had been geometrically rectified and superimposed on the German Gauss-Krüger coordinate system at a scale 1:200,000, sheet CC7110, Mannheim (HABERÄCKER et al., 1980).

The maps were digitized by scanning 6x6 cm slides with the DICOMED flying spot scanner of the DIBIAS System. This system allowed a pixel size of about 350 x 350 m which corresponds approximately to the accuracy of the maps employed.

Geometric correction of the HCMM thermal image. 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.
Details of the procedure are given in TELLUS NEWSLETTER 12 (Annex 2).

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

Seventeen control points were used for the "rough" rectification, seven of which were on the Rhine river, 2 on prominent corners of forests and 8 in the bends of valleys and valley confluences of the highlands.

For the "fine" rectification an accuracy of 600 m or less was required for the control points. 86 points could be found, of which 8 belonged to bodies of water, 5 were urban built up areas, 18 represented band use boundaries and 51 were given by topography.

Results. The residual error after the "fine" rectification was of the order of one pixel or less. The best results, 588 m and 522 m in the line direction and 396 m and 456 m in the column direction, were obtained for two maps at 1:200,000 of Freiburg, a region the authors were especially well acquainted with.

The examples presented for the geometrical rectification of HCMM-data with a residual error of less than one pixel are, in our opinion, the best that can be achieved with the algorithms used. Better results could be obtained with the digitizing of the maps, if devices existed which allow scanning without a reduction in the size of the maps and without the photographic discrimination of the gray levels.

A first evaluation of the geometrically corrected scene in the form of relief, land use and built up areas is presented in TELLUS NEWSLETTER 12 (Annex 2). Even after this first evaluation it can be concluded that it is extremely useful to combine rectified HCMM thermal data with thematic maps or pre-processed LANDSAT images.

4.2.2. Anthropogenic heat release (UF/GI)

A first evaluation of the usefulness of HCMM thermal data for defining the surface temperature of built-up areas was carried out on scene AA0034.0213.0.3 (May 30, 1978) for the city of Freiburg (48°N, 9° 50' E).

After geometric correction of the data on a scale 1:200,000 and smoothing of the pixel edges, the resulting image was compared with surface temperatures measured with an airborne thermal scanner from a hight of 4000 m. The results are presented in Figs. 4a and 4b.

Though the dates of the aircraft and satellite scene are different and, also due to the uncertainties in the calibration of the HCMR, there is no possibility to compare absolute temperatures, the temperature pattern on the two scenes is rather similar.

It is hoped that this first promising result will be confirmed for additional built up areas.

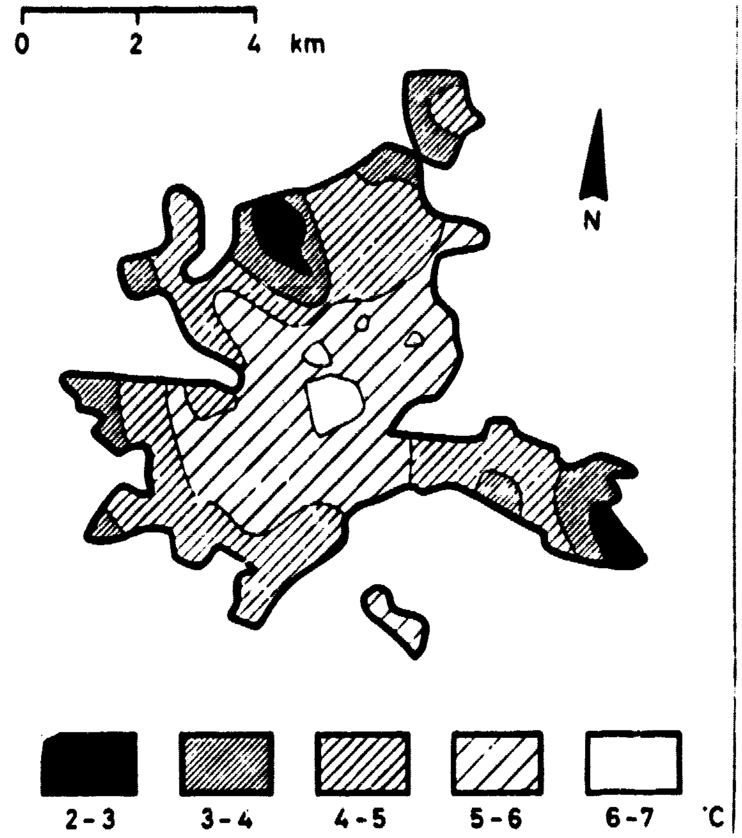


Fig. 4 a: Surface-temperature distribution within the city of Freiburg on 5/30/79, 2:13 GMT (preliminary calibration), as revealed by the HCMM thermal-image following "fine" rectification and "smoothing" of the pixel edges.

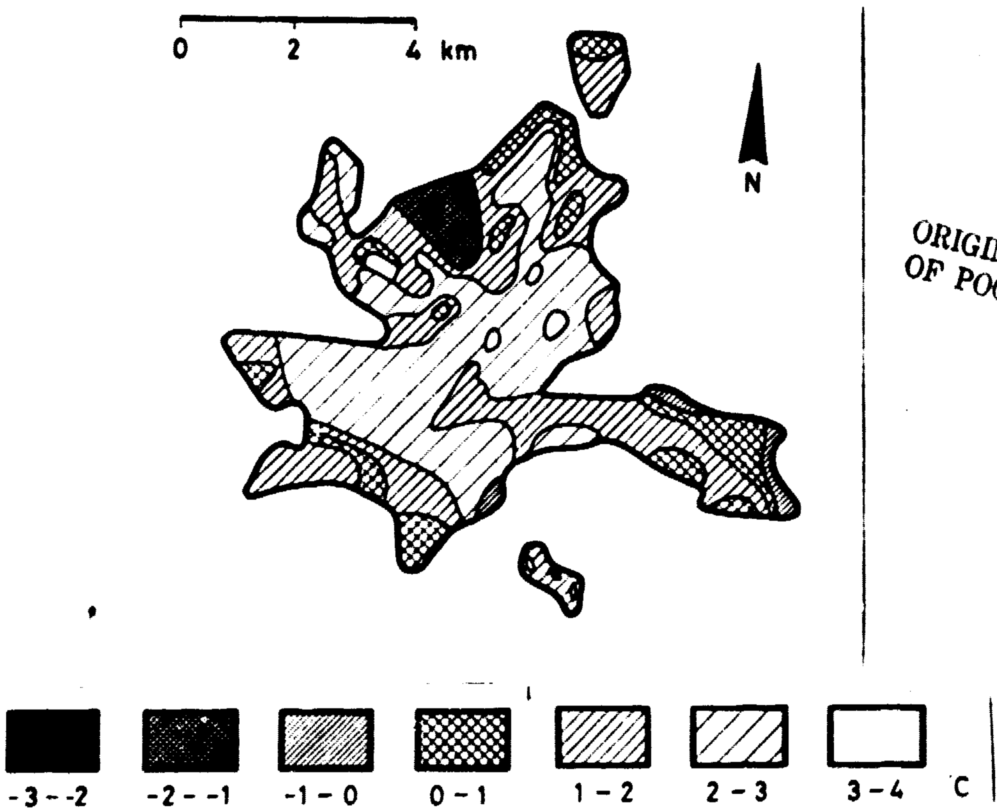


Fig. 4 b: Surface-temperature distribution within Freiburg, taken from an aircraft scanner thermal image from 4/1/76 3:40 GMT, 4 000 m height above ground, resolution of the original pixels: 10 m.

4.3. Satellite Data Calibration and Atmospheric Corrections

4.3.1. Validation of HCMR calibration

A number of attempts have been made to validate the calibration of the thermal channel of the HCMR by comparing ground measured surface temperatures with the temperatures given by the spacecraft's radiometer.

Ideally, these comparisons should be carried out both over a large range of temperatures and over a long time period. In practice, this combination is impossible to be realized and is, fortunately, also not necessary. Temperatures are, for example, much lower in winter than in summer and, therefore, for this time of the year the high range of the calibration curve is of no practical interest.

The following conditions should be fulfilled by a reference surface:

- large, at least 25 pixels or more, to eliminate border effects
- homogeneous surface temperature
- radiometric measurements of the surface temperature or knowledge of the emissivity
- radio soundings in the vicinity to provide data for atmospheric corrections
- a reasonably large number of HCMM scenes spaced out over the life time of the satellite.

A number of reference sources covering a wide range of temperatures should be available.

Large water bodies can fulfill a few of these conditions reasonably well, though they provide at a given time a rather narrow temperature range.

Accordingly, of the present validation attemps, four relied on water surfaces, one used the energy balance of a forest and one employed the surface temperature routinely measured on airfields.

4.3.1.1. Water surfaces

4.3.1.1.1. North Sea and Ijssel Meer (ICW)

Open water temperatures were measured in the North Sea off the coast of the Netherlands and in the Ijssel Meer. No correction for emissivity was applied. They were compared with HCMM surface temperatures measured on July 31, 1978, scene AA0096.1226.0.1,2.
Atmospheric corrections were applied using the RADTRA model with data from atmospheric soundings from KNMI De Bilt. The results given in Table 8 show HCMM temperatures to be lower by 4-6°C than ground measured temperatures.

Table 8

	Temperatures, °C			
	HCMM	Correction	HCMM corrected	Ground measured
North Sea	11.5	- 0.5	11.0	15.0
Ijssel Meer	14.0	+ 2.0	16.0	22.0

4.3.1.1.2. Adriatic Sea (JRC)

The sea surface temperature was measured from an oceanographic platform situated off the coast of Venezia (45° 19' N, 12° 31' E).
The measurement was carried out with a PRT-5 radiometer, vertically 8-10 m above the sea surface and simultaneous with the passage of the satellite. During the daytime passage the transmittance of the atmosphere was likewise measured with an 4 channels LANDSAT-compatible radiometer (EXOTECH mod. 100).
The HCMM surface temperature was taken as the mean of 58 pixels around the platform with a standard deviation of 0.4°C. Atmospheric corrections were calculated with the RADTRA model using atmospheric soundings from Udine, 100 km to the N.E. of Venezia.

Date: Oct. 6, 1979

HCMM scene: Orbit 7823, track 15D, row 3 (obtained from

Table 9

Time GMT	HCMM C°	Correction C°	HCMM corec-ted, °C	Ground C°
11.28	11.0	+ 1.5	12.5 ± 0.4	17.8 ± 0.2
22.00	-	-	-	17.1 ± 0.1

These temperatures are radiometric temperatures.
The HCMM temperature is again lower by about 5°C than the ground measured temperature. Differences in the sea surface temperature between day and night were of the order of 0.7°C.

4.3.1.1.3. Gulf of Lyon (JRC)

This validation attempt consists only in the comparison of a consecutive N/D pass of HCMM and of measurements by NOAA-5. Superposition of the scenes was carried out by CTAMAN - Ecole des Mines, Sophia-Antipolis. No measurements of the actual sea surface temperature were employed and, therefore, no atmospheric corrections were introduced.

Area : 643 NOAA-5 pixels, South of Marseille

Date : July 17, 1978

HCMM scenes: AA.0082.0208.0.3
AA.0082.1340.0.1,2

NOAA-5 passage: 08.35 GMT

The temperatures below are radiative temperatures in °C:

HCMM/N	NOAA-5	HCMM/D
14.1 ± 0.5	26.3 ± 0.5	16.5 ± 0.8

The difference between the two satellites is 10 + 12°C, between D and N HCMM passages is 2.4°C which could partly

be due to atmospheric effects and partly reflect the warming of the sea surface.
Speculating about what should be the time sea surface temperature, its value would probably be around 20-23°C. This would leave HCMM by about 5°C too low and NOAA-5 by a few degrees too high.

4.3.1.2. Land surfaces

4.3.1.2.1. Airfields in Belgium (KUL/LBB)

Fourteen Belgian airfields where ground temperature is monitored continuously could be identified on HCMM scenes by the superposition of computer printout maps and road and/or topographic maps. Both the visible and IR-channel were used in this process.

HCMM scenes: AA0034.0213.C.3 of May 30, 1978
of September 16, 1979 (provided by CMS Lannion).

Both scenes were of good quality and showed the Belgian territory to be completely cloud free.

Ground measurements. Ground temperatures at a depth of 2, 5, 10, 20, 50 and 100 cm are continuously recorded on airfields by the Belgian Civil Aviation Board, Directorate of Meteorology. The measurements are made with electrical resistance thermometer.
The temperature at the 2-cm depth (grass covered soil) was used for comparison.

Results. Limiting the comparison to 5 airfields for the night pass of May 30, 1978 and to 8 airfields for the day pass of Sept. 16, 1979 two linear regressions of satellite temperature on ground temperature could be established. The regressions are shown in Figs. 5 and 6. They indicate an underestimate of the ground temperature by 4.5°C in May 1978 and of 9.3°C in Sept. 1979.

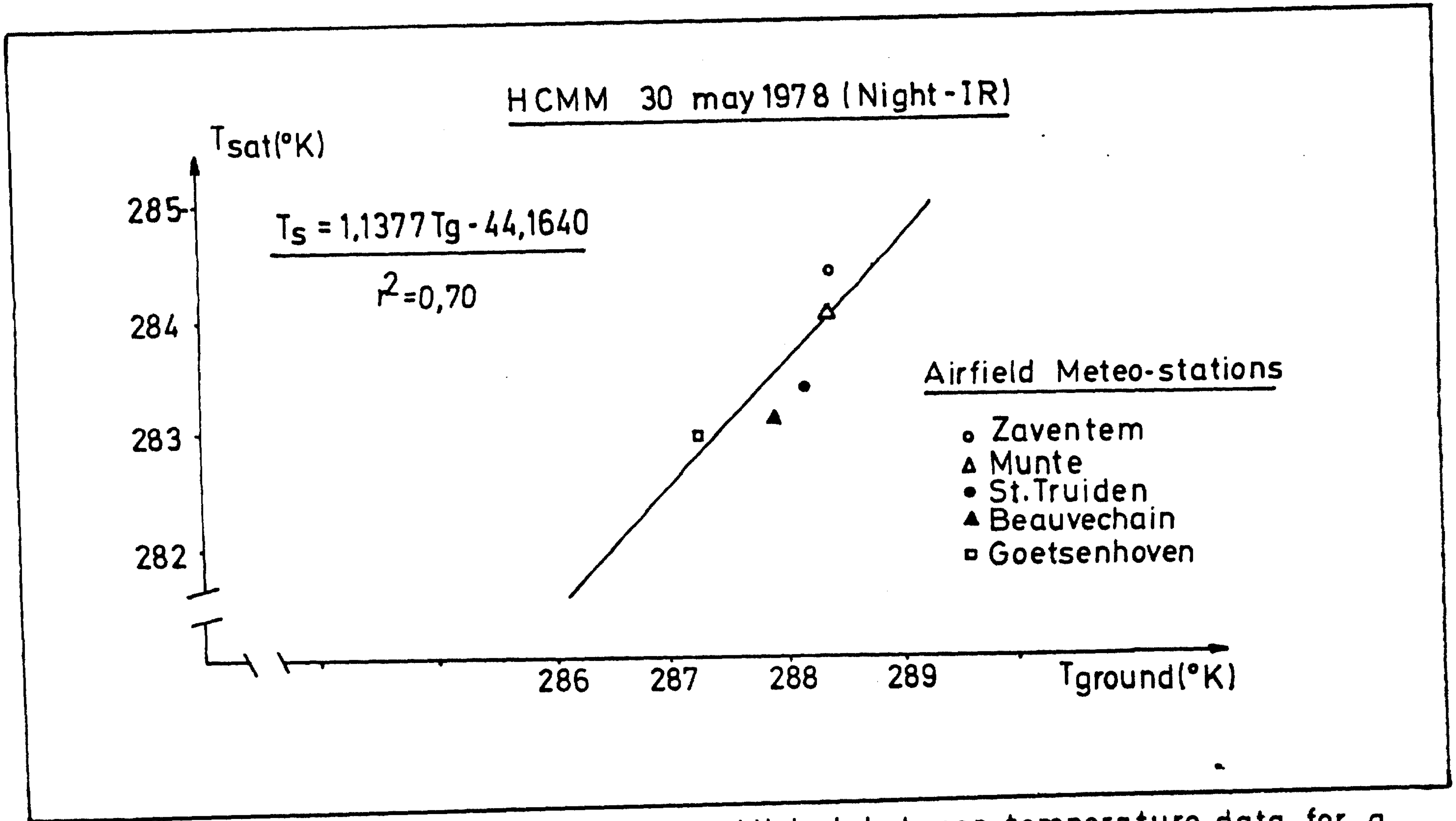


Fig.5 : The linear regression equation established between temperature data for a HCMM-pass on 30 may 1978 (Night-IR) over Belgium.

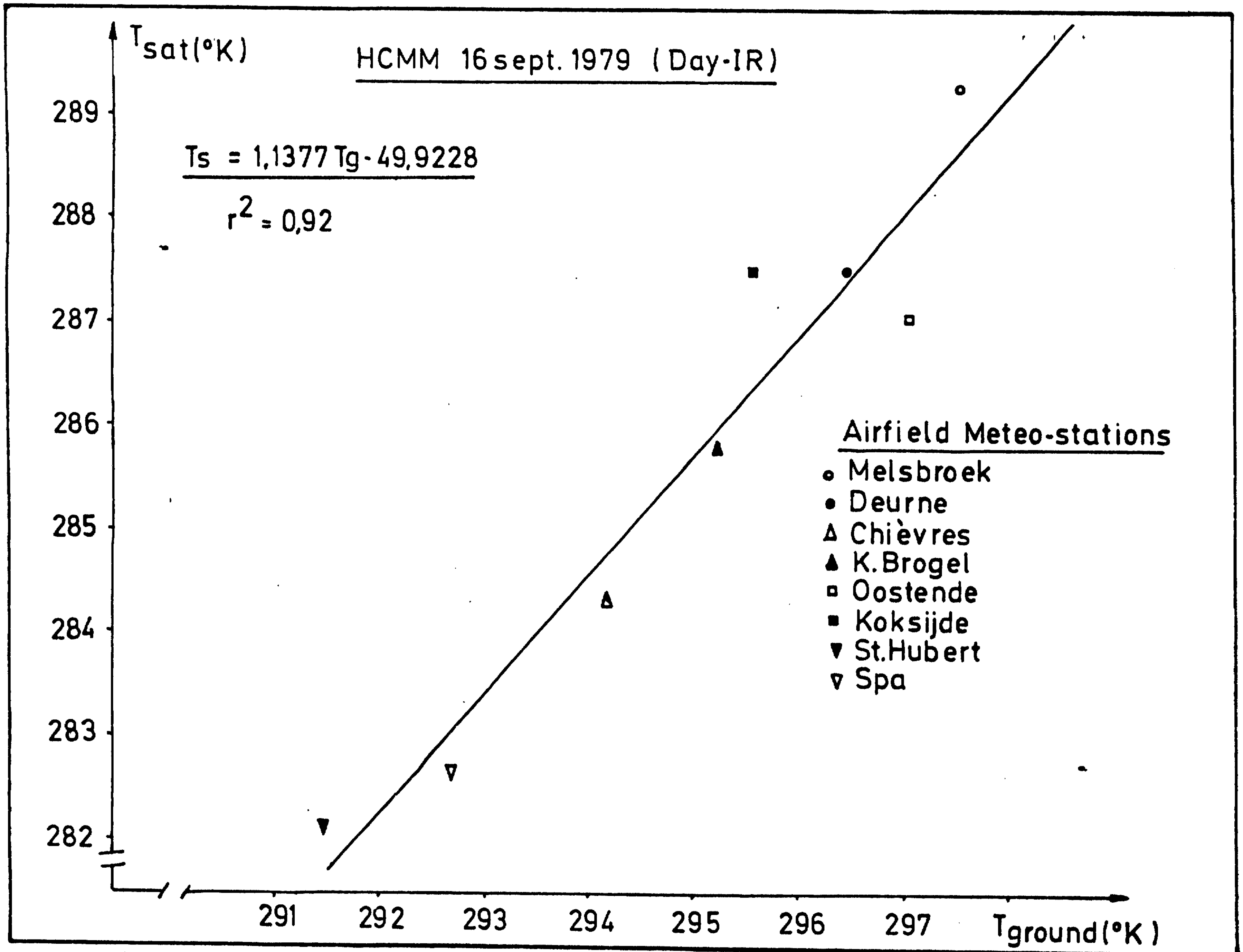


Fig.6 : The linear regression equation between temperature data for a HCMM-pass on 16 sept 1979 (Day-IR) over Belgium.

Atmospheric corrections they were calculated at the JRC for both scenes by the RADTRA model using radiosonde data from UCCLE shown in Fig. 6 . These corrections were negative for the night of May 30, and positive for the day of Sept. 16.

Applying a further correction for an emissivity of 0.989 for grass (BECKER et al., 1980), the data from the two dates could be represented by one linear regression lire as shown in Fig. 7
Ground temperature is underestimated by the HCMR by 5.5°C.

4.3.2. Atmospheric corrections

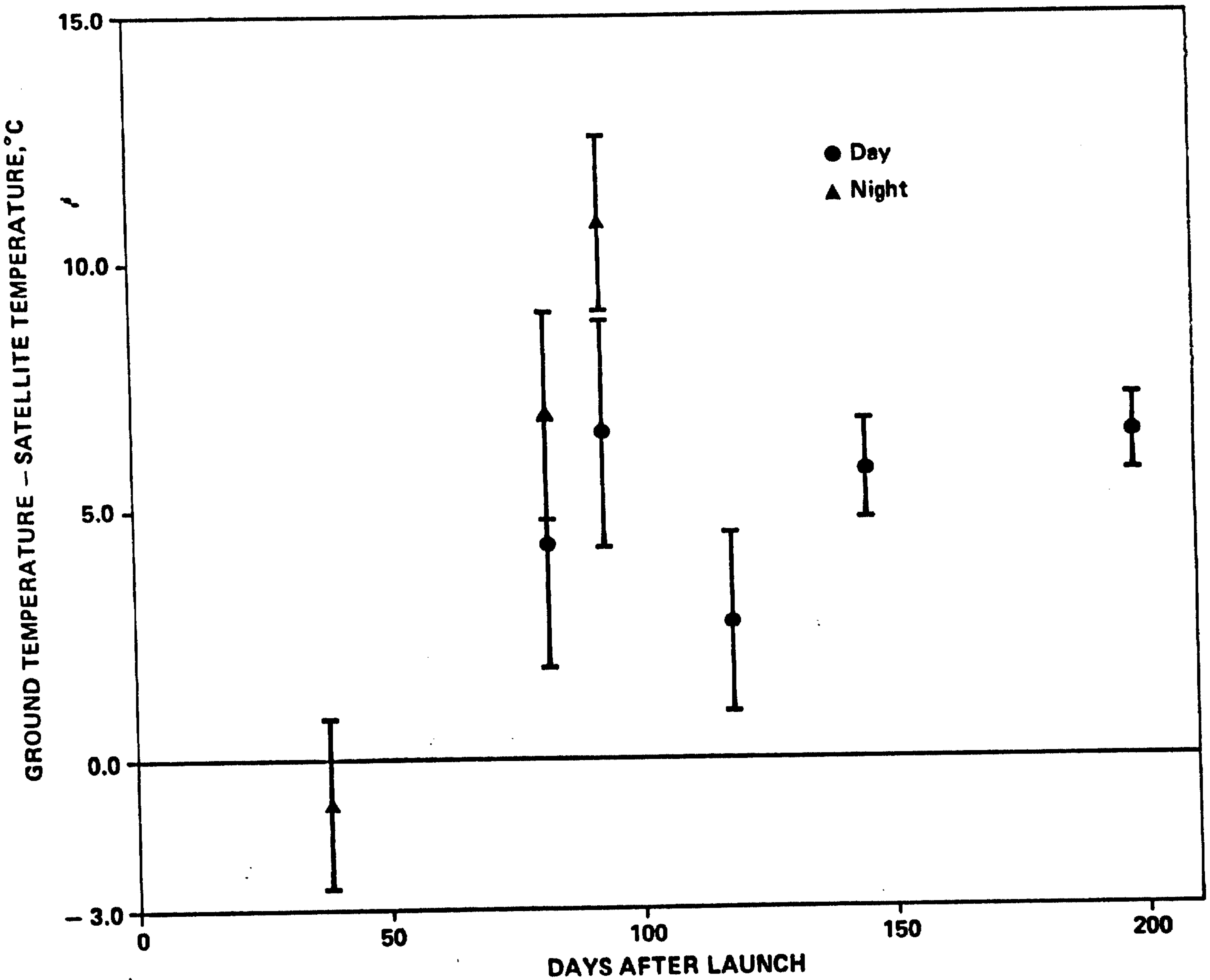
4.3.2.1. Comparison of atmospheric transfer models (ICW)

The performance of the RADTRA model provided by NASA to HCMM investigators was compared to that of a simplified model of Becker (1978). This latter model is based on thermal measurements at two wavelengths.

Agreement between the models was good for surface temperatures which were about equal to the temperature of the lower atmosphere. For higher surface temperatures the two channel model seemed to underestimate the atmospheric correction.

Mean transmission coefficients were calculated for the 10-14 μm band employed in aircraft scanners and the 10.5-12.5 of the HCMR.

It was found that in the RADTRA model, the value 3.2 for the mass absorption coefficient K2 should be replaced by 10. The HCMM Project Scientist has already been informed of this finding.
Further details are presented in TELLUS NEWSLETTER 14 (Annex 4).



GROUND TEMPERATURE – SATELLITE TEMPERATURE, °C
15.0
10.0
5.0
0.0
– 3.0
0
50
100
150
200
DAYS AFTER LAUNCH
● Day
▲ Night

Fig. 7

5. ABBREVIATIONS

AEM	Application Explorer Mission
AL	After Launch
ATI	Apparent Thermal Inertia
CC	Cloud Coverage
CCT	Computer Compatible Tape
CMS Lannion	Centre d'Etude de Météorologie Spatial de Lannion
COI	Co-Investigator
DIR	Day Infrared
DV	Day Visible
D	Day
EC	European Communities
EARTHNET	
ESA	European Space Agency
ET	Evapotranspiration
GMT	Greenwich Meridian Time
GSFC	Goddard Space Flight Center
GDTA	Groupement pour le Dévéloppement de la Télédét. Aérospatiale
HCMM	Heat Capacity Mapping Mission
HCMR	Heat Capacity Mapping Radiometer
HET	HCMM Experimental Team
HOM	Hotine Oblique Mercator Projection
HD	High Density
IPF	Image Processing Facility
HDT	High Density Tape
ID	Identification
IR	Infrared
IFOV	Instantaneous Field of View
IGN	Institut Géographique National
JFE	Joint Flight Experiment
JRC	Joint Research Centre
LAT	Latitude
LONG	Longitude
MSS	Multispectral Scanner

NIR	Night Infrared
NT	Negative Transparency
N	Night
NER	Noise Equivalent Radiance
ND	Night-Day
NDN	Night-Day-Night
PC	Priority Coverage
PI	Principal Investigator
PR	Progress Report
PPL	Priority Processing List
QL	Quick Look
RO	Retrospective Order
SEAL	Simplified Evaporation Algorithm
SC	Spacecraft
SO	Standard Order
TD	Temperature Difference
TI	Thermal Inertia
TNL	TELLUS Newsletter
TRK	Track
TS	Test Site
TSC	Test Site Coordinator
USWCL	U.S. Water Conservation Laboratory, Phoenix, AZ.
VIS	Visible
WG	Working Group

6. ANNEXES

1. TELLUS NEWSLETTER 11

   J. Huygen. Further developments of the TELL-US model:

   I. An implicit finite difference scheme for the numerical approximation of the ground heat flux.

   II. A simple algorithm for estimating the actual and potential evapotranspiration of vegetated surfaces from one remotely sensed surface temperature near the daily maximum.

   Novembre 1979.

2. TELLUS NEWSLETTER 12

   H. Gossmann and P. Haberäcker. Image processing of HCMM thermal images for superposition with other satellite imagery and topographic and thematic maps.
   January 1980.

3. TELLUS NEWSLETTER 13

   A. Perrier, B. Itier, P. Boissard, C. Goillot, P. Belluomo and P. Valéry. A study of radiometric surface temperatures: their fluctuations, distribution and meaning.
   (French, english summary).
   February 1980.

4. TELLUS NEWSLETTER 14
   G.J.A. Nieuwenhuis. Influence of the atmosphere on thermal infrared radiation.
   May 1980.

5. TELLUS NEWSLETTER 15

   M. Menenti. Defining relationships between surface characteristics and actual evaporation rate.
   May 1980.

6. TELLUS NEWSLETTER 16
B. Seguin and V. Petit. The evaluation of evaporation by infrared thermography : A critical analysis of the measurements on the Crau test-site.
June 1980 (French, english summary).

7. J.M. Grégoire. Détermination de l'évapotranspiration d'un couvert végétal herbacé et de l'humidité de surface du sol : Apport de la télédétection.
Thèse de 3ème cycle. Université Louis Pasteur de Strasbourg. 1979.

8. W. Klaassen. The use of thermal infrared remote sensing for the mapping of groundwater levels.
E.A.R.S. b.v. Delft, the Netherlands (in Dutch).
1980.

7. REFERENCES

1. Hlavek, R. et al., 1974. Essais d'estimation de l'évapotranspiration réelle à l'échelle du bassin versant : considérations théoriques et applications pratiques.
Bull. AIMS : N. 19(4), pp. 449-485.

2. Perrier, A. 1977. Projet de définition concernant l'évapotranspiration en fonction de considérations théoriques et pratiques.
La météorologie, VIe série, N° 11, p. 7-16.

3. Jackson, R.D., Reginato, R.J. and Idso, S.B., 1977. Wheat canopy temperature : A practical tool for evaluating water requirements.
Water Resources Res. 13 (3), p. 651-656.

4. Hechinger, E. 1979. Contribution à l'interprétation de données de télédétection : étude d'un modèle thermique de sols et de son emploi pour la réalisation d'images de télédétection dans le visible et l'infrarouge thermique.
Ph.D. Thesis, Université Louis Pasteur de Strasbourg, pp. 125.

5. Haberäcker, P. et al. 1980. Auswertung von Satellitenaufnahmen für die Landnutzung. Schriftenreihe "Raumordnung" des Bundesministers für Raumordnung, Bauwesen und Städtebau, Bonn.

6. Becker, F., Ngai, W. and Stoll, M. 1980. An active method for measuring thermal infrared effective emissivities. Implications and perspectives for remote sensing.
COSPAR, Budapest (in print).

7. Becker, F. 1978. Température superficielle de la mer et la transmission atmosphérique par radiométrie différentielle.
Sci. Techn. CNEXO : Actes colloq. N° 5, pp. 141-160.