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

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First Progress Report

April 1st - August 31th, 1979

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Summary

The present report covers essentially the pre-launch phase of the TELLUS Project.

In this period, algorithms for the interpretation of remotely sensed surface temperatures were developed (6.2.1.3). These are the TERGRA model (6.2.1.3.2) for the calculation of evapotranspiration and soil moisture of vegetated areas and the TELL-US model (6.2.1.3.3) for the evaluation of evaporation and soil moisture of bare soil or scarcely vegetated areas. Additional methods for the calculation of regional evapotranspiration were also evaluated (6.2.1.3.4).

Experience in the interpretation of thermal data was obtained in flight campaigns in the Netherlands, France and the United Kingdom and in long term field measurements in France and Italy (6.2.2). These campaigns permitted the test and application of the interpretation algorithms and permitted the development of data processing routines.

The use of HCMM data for studies of a regional heat budget was simulated from aircraft data. Likewise, the identification of frost prone areas and the influence of wind on remotely sensed surface temperatures have been investigated (6.3.1).

The HCMM data products received were generally of good quality (5.1.3). Only a visual interpretation regarding geomorphologic and topographic features has been carried out so far (6.2.1.2).

1. INTRODUCTION

The main objective of the TELLUS Project is the development and presentation of remotely sensed data on earth resources. This will permit the Commission of the European Communities (EC) to comparatively evaluate the potential and benefits of air-and-space observation systems for obtaining information required for various sectors of its common policy.

An attempt will be made to learn whether HCMM data, together with other existing aircraft and satellite data had a significant advantage over conventional methods for providing the Commission with this information. In this sense, the TELLUS Project should give a practical demonstration on a European basis. Thus it is being developed as a pilot experiment aimed to cover a range of significant European conditions regarding agriculture, hydrology, geology and the environment.

Furthermore, set up as a collaboration of several national Institutes and Organizations working together under the leadership of the EC's Joint Research Centre (JRC) Ispra Establishment, the TELLUS Project permits the concentration of diversified competences and support facilities for the comparative study of various typical European test sites. This form of collaboration was chosen both for reasons of efficiency and for promoting Remote Sensing methods within the European framework.

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.

2. FRAMEWORK OF COINVESTIGATORS

The list of the Organizations and Institutes participating in the TELLUS Investigation (HCM-025) is reported in Table 1, together with the names of Co-Investigators.

The Co-Investigators are divided into six groups:

EC General Directorates and JRC (Ispra Establishment)
Benelux Institutes
British Institutes
French Institutes
German Institutes
Italian Institutes.

TABLE 1 : LIST OF ORGANISATIONS 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*	
	O'Hoore J.M.	• Fakulteit der Landbouwwetenschappen, Kath. Universiteit, Leuven	KUL/LBB
		Denmark	
	Eckardt F.E.*	• Institutet for Økologisk Botanik, University of Copenhagen	UK/IOB
Goillot Ch.		*France*	
	Goillot Ch.	• Service de Télédétection, INRA Versailles	INRA/ST
	Barloy E.	• Station d'Amélioration des Plantes, INRA Rennes	INRA/SAP
	Seguin B.	• Station 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
Böhnel H.J.		*Germany*	
	Gossmann H., Weischet W.	• Geographisches Institut der Universität, Freiburg	UF/GI
	Böhnel H.J.	• Institut für Physikalische Weltraumforschung, Freiburg	IPW
	R. van der Ploeg	• 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
	Pietracaprina A.	• Istituto di Mineralogia e Geologia, Università 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
	Wisse J.	• 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

* *No receiving station for the Greenland test-site*

3. TEST SITES

The TELLUS test sites are reported in Table 2. Geographic as well as technical considerations led to regroupe them in 5 groups according to the Institutes involved and to designate for each group one Co-Investigator as test site Coordinator. Names of test-site Coordinators are reported in Table 1.
Fig.1 shows the location of the TELLUS test sites within the European coverage area of the HCMM receiving stations of MADRID (NASA) and LANNION (ESA). The "diamond" on the right hand side of Fig.1 encloses twelve hour night/day coverage pattern due to the intersection of the corresponding satellite orbites.

4. OBJECTIVES OF THE INVESTIGATION

According to the interest of the EC's Commission and the proposals made by the national Institutes, three main thematic lines of investigation have been singled out:

1. Evaluation of evapotranspiration and moisture content of bare soils and soils covered by vegetation
2. Study of the interactions between natural phenomena and mesoscale heat budget
3. Man-made changes and their impact on regional heat budgets.

Tables 3 - 5 summarize the research subjects and objectives of the TELLUS Co-Investigators.
Estimates of soil moisture content and of evapotranspiration can lead to considerable cost savings, by a more effective planning of water supply, irrigation and drainage systems.
The knowledge of soil moisture content is important for both dry areas and for moisture saturated zones. In the first case, lack of water in soils narrows the range of profitable crops, causes crops stress and reduces crop yields.
In the second case, saturation of soil is important both from an agricultural point of view and for monitoring flooding. Accelerated erosion is also influenced by the distribution of areas of high soil moisture and the depth of the ground water table.

The heat budget is a relevant environmental characteristic due to its impact on vegetation and man. Agricultural productivity may be strongly affected by variations in the regional heat budget due to both man-made and natural (i.e. meteorologic) causes.
Urban and industrial areas (factories, power stations) can significantly affect the heat balance of water bodies and surrounding farmland and woodland. The evaluation of the heat budget on a regional scale with

Test Site Group/Country	Test Site	No.
ITALY	Puglia	1
	Sardegna	2
	Emilia	3
FRANCE	Bouches du Rhône	4
	Bretagne	13
GERMANY	Rhine Valley	5
	Rhine Valley	6
	Northern Alps	7
UNITED KINGDOM	Basilicata (Italy)	1
	England	8
	Wales	9
	England	10
	England	11
BENELUX	Benelux	12

Table 2. TELLUS test sites, arranged in groups.

HEAT CAPACITY MAPPING MISSION (HCMM) 12-HOUR NIGHT/DAY COVERAGE

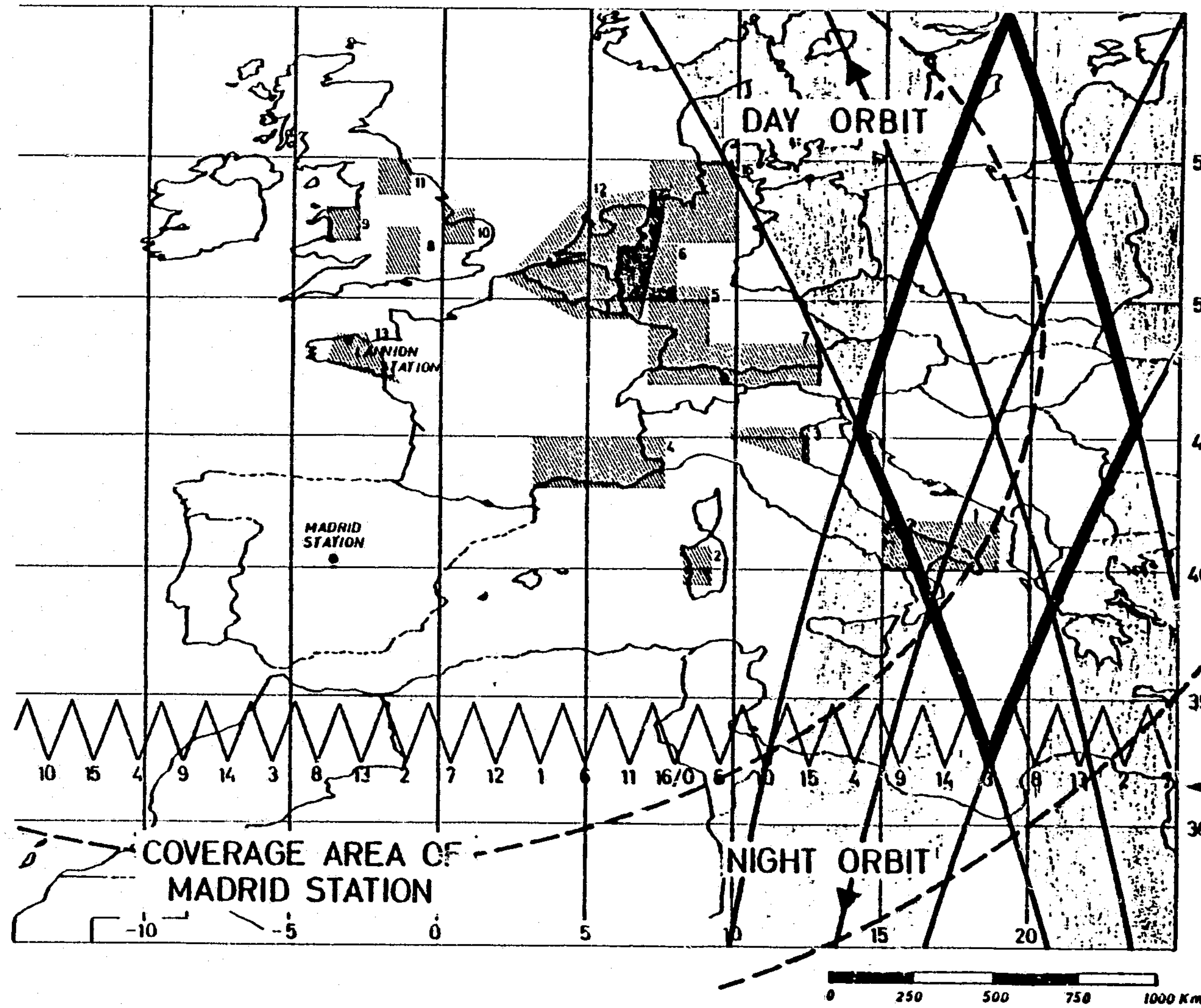

Figure 1 Spatial distribution of TELLUS test sites within the European coverage area of the HCMM receiving stations of Madrid and Lannion

Table 3. Soil Moisture and Evapotranspiration

COI-Group/Co-Investigator	Research Subject/Objectives	Test Sites
BENELUX FRANCE GERMANY ITALY U.K. all Co-Investigators	Mapping soil moisture and evapotranspiration with the aid of remotely sensed surface temperatures and routinely measured agrometeorologic data. Objectives: Development and testing of algorithms relating surface temperature to soil moisture and ET. Evaluation of the usefulness of these algorithms in agriculture, hydrology and ecology.	All test sites
BENELUX FRANCE GERMANY ITALY U.K. all Co-Investigators	Influence of atmospheric effects on remote sensing in the thermal infrared range. Objectives: Evaluation of the errors caused by the atmosphere on thermal infrared measurements and development of methods to correct these errors.	All test sites
ITALY IGA USS/ICA USS/IMG UK IHW UL/DG	Identification of water saturated zones Objectives: Evaluation of the efficiency of a remote sensing system for flood control and the design of drainage systems.	2,3,9,10,11
UK UR/DG	Identification of erosion prone areas. Objectives: Establish relations between areas of high surface humidity and accelerated erosion in order to permit a more adapted agricultural development and planning of road systems.	1

Table 4 Man-made Changes and their Impact on Regional Heat Budget

COI-Group/Co-Investigators		Research Subject/Objectives	Test Sites
GERMANY	IPW UF/ GI	Evaluation of changes in the regional heat budget caused by modified land use. Objectives: Evaluate the use of satellites (HCMM, LANDSAT, TIROS-N) for the periodic control of the regional heat budget.	5,6,7,8
GERMANY	IPW UF/ GI	The influence of atmospheric pollution on long term changes in the regional heat budget. Objectives: Evaluation of heat island and greenhouse effects on agricultural and woodland areas.	5,6,7,8
GERMANY	IPW	Identification of heat sources and liquid and gaseous effluents. Objectives: Evaluation of the possible use of HCMM and other satellites in the identification of urban and industrial areas and water bodies.	5,6,7,8

Table 5 Natural Phenomena and their Impact on Regional Heat Budget

COI-Group/Co-Investigators	Research Subject/Objectives	Test Sites
FRANCE INRA/VER GERMANY UF/GI	Low atmospheric layer movements created by non-uniform surface temperature distribution Objectives : Mapping of frost prone agricultural areas	4, 5
ITALY IGA UCEA	Hail storms Objectives: Establish a correlation between thermal, hydrologic and topographic characteristics of land surfaces and the formation of hail storms.	3
BENELUX KNMI	Heat budget and atmospheric boundary layer. Objectives : Use of HCMM data for a better understanding of regional heat budgets.	12

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mixed rural and industrial activities is one of the important steps in the conservation of environmental quality.
Evaluating and monitoring the tendency to frost of agricultural areas and correlating between thermal, hydrological and topographical characteristics of band surfaces and the occurrence of hail storms are two among the subjects for investigation where not man, but nature influences the regional heat budget.

5. DATA RECEPTION AND DISTRIBUTION

HCMM data reaching JRC can be divided into two groups:

1. Data as stipulated in the Provisions for Participation i.e. test or preliminary data, standing order data (SO) and retrospective order data (RO)
2. Quick-look (QL) data as stated in the Freiburg Meeting of WG 3 (Dec. 1978).

5.1 Data according to Provisions for Participation

JRS has received only test data from NASA-GSFC until the end of 1978 in the form of positive prints and transparencies 24x24 cm, DIE/DVIS and NIR and a number of corresponding tapes.

Delivery of standing order format data in the form of negative 24x24 transparencies started at the beginning of 1979. A complete list of SO data received is given in Table 6 .

No RO data has been received up to now.

5.1.1 Data transmission

A flow-chart of the data transmission is presented in Fig. 2 . HCMM data are sent by regular mail from GFSC to the EC Washington Delegation. From there they are forwarded by diplomatic pouch via Brussels to JRC Ispra. Travel time from GSFC to JRC did not exceed 16 days.

Dispatching of the data to the various test site coordinators is carried out at Ispra as follows:
In order to localize the test sites, SO transparencies are superposed on a transparent map of Europe carrying the geographic coordinates and the contours of the test sites.

Problems have been arisen to crrectly localize images with heavy cloud cover when erroneous coordinates were indicated on the images.

TABLE 6 :

Priority Processing List (PPL) and shipments received at JRC

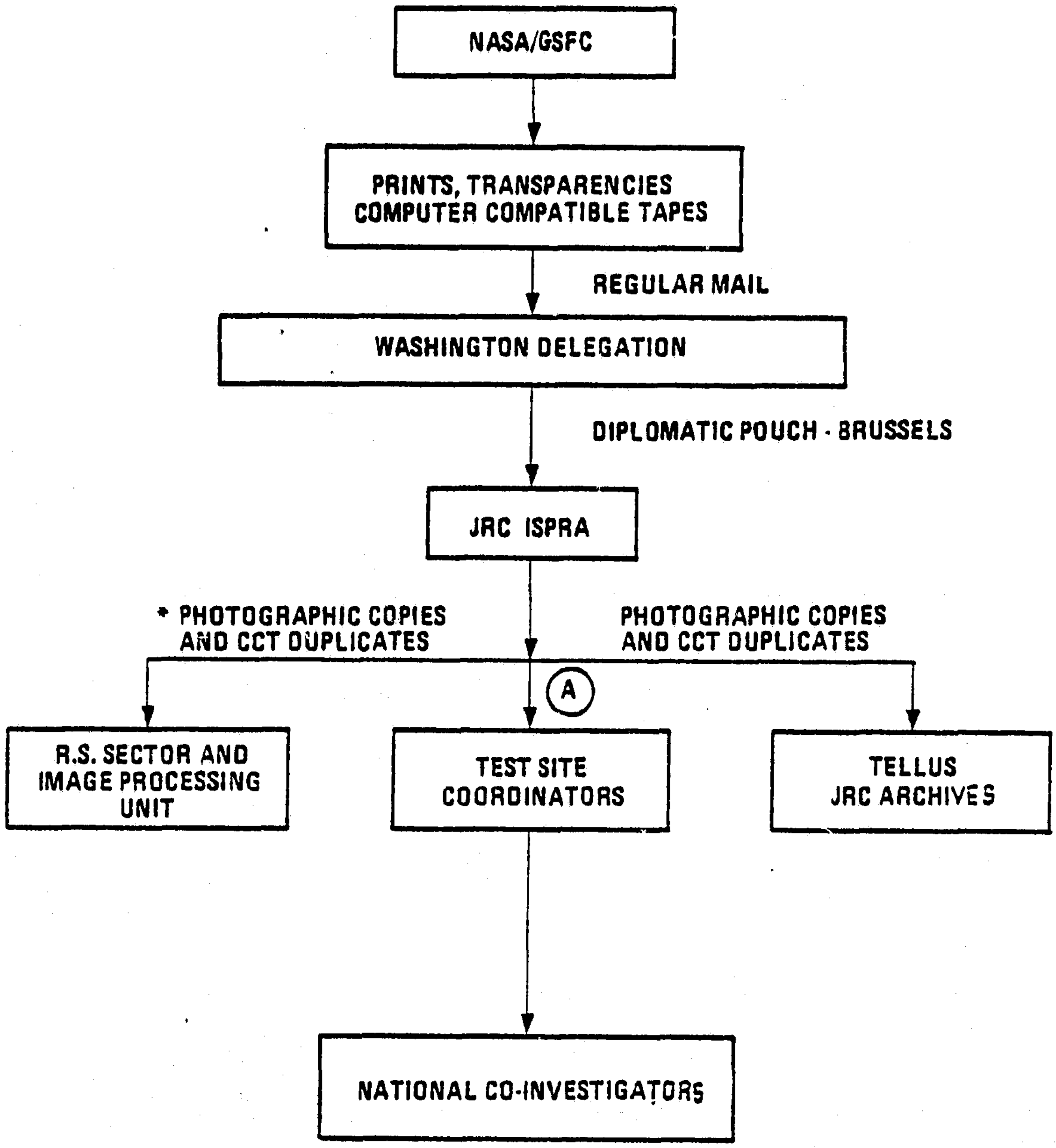
A L	Date	Test-sites		Track
22	18.05	2, 3		5 (1978)
24	20.05	3	F	7
26	22.05	1		9
27	23.05	3		10
29	25.05	3	F	12
31	27.05	1		14
33	29.05	3	D	16
34	30.05	3	D	1
35	31.05	3	F	2
38	03.06	2		5
42	07.06	1		9
43	08.06	3		10
45	10.06	3	F	12
47	12.06	3		14
54	19.06	2, 3		5
55	20.06	3	D	6
58	23.06	1		9
59	24.06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

Symbols and abbreviations:

A L	after launch (no. of days)
d	failed track, day
n	failed track, night
	shipment received

Test-sites for NASA PPL request:

1 :	Basilicata, Puglia	B :	Benelux
2 :	Sardegna	D :	Germany
3 :	Rest of Europe	F :	France
		UK :	United Kingdom



* On specific request

FIG. 2 : HCMM DATA DISTRIBUTION FROM GSFC

5.1.2 Data received

The first SO received was processed on January 25, 1979, the last one on June, 1979.
The data recived correspond to 49 orbits relevant to the investigation and are distributed as listed in Table 6 . In this table, the "presence" of a test site group indicates that at least a part of one test site of the group was covered by the track, regardless of cloudiness.

5.1.3 Data quality

Data quality is ummed up in Table 7 .

	test images	SO images	Last SO images
Scanning	good	good	good, intermittent poor
Optical quality	good but low contrast	good	irregular
Densitometric quality	low	very good	good when scanning is good
Cloudcover	irregular	intermittent	very irregular

Table 7 : Data quality

5.1.4 General remarks

The end of January 1979 GSFC asked JRC to produce a priority processing list (PPL) because of the long delay in SO delivery.
This list (Table 8) was established according to the requests of the co-investigators and was sent to GSFC in February 1979.
Up to now only 20 out of 80 priority requests have been received. Inquiries as to the criteria used in processing images received no reply.
The PPL was also communicated to Lannion with a request for retrospective quick-looks. This request could not be fulfilled as the station is at present fully occupied with the production of 1979 QL.

TABLE 8 :

Presence of European groups of test sites on the S.O. images transmitted to JRC Ispra, then dispatched to the various co-investigators

No. of tracks	Date 78	Night exposure					Day exposure					Consecutive night/day
		B	F	I	D	UK	B	F	I	D	UK	
0/16	06.30	+	+	+	+							
	10.03								+			
	12.07						+	+	+	+		
1	07.17	+	+		+	+						
	10.05						+	+	+	+		
	12.08								+			
2	07.02	+	+			+						
	08.19		+									
	12.25							+	+		+	
3	12.26		+									
4	06.18						+		+	+		
	08.21			+								
	09.06						+		+	+		
	11.09		+			+						
5	06.03		+	+	+							
	06.19	+	+	+	+	+						
	07.05	+	+	+	+		(+)	+	+	+		+
	09.07						(+)	+	+	(+)		
6	06.20	+	+		+							
	07.06	+	+		+							
	07.22		+		+							
	12.29						(erratic)					
7	08.24							+				
	10.27							+				
	12.30							+				
8	10.28							+			+	
9	06.07			+	+							
	07.09								+	+		
	09.27					+						
	10.29									+		
10	06.24						+		+	+		
11	07.06	+	+	+	+							
	10.30						+		+	+		
	11.16	+	+		+							
13	10.17										+	
	11.02							+			+	
14	05.11		+			+						
	08.15		none									
	08.31							+				
	10.18		none									
	11.13							+				
	12.15								+	+		
	12.21							+				
15	07.31	+			+	+						
	09.01						+		+	+		
	11.04								+	+		
	12.06						+		+	+		
	12.22								+			
TOTAL		10	15	7	12	6	19	13	18	13	4	1

5.2 Quick-looks

After the signature of an agreement between ESA and the French government in May 1979, CMS Lannion started to produce negative transparent QL. They are dispatched regularly at fortnightly intervals from CMS Lannion directly to the various test site coordinators. A flow diagram of the distribution is shown in Fig. 3 .
The quality of the data is good. QL are produced irrespective of cloud conditions.

6. ACTIVITY PERFORMED AND RESULTS OBTAINED

6.1 Generalities

In 1976 the TELLUS Project was decided to be conducted in two phases: 1) pre-launch, 2) post-launch and continuing investigations.
However, owing to the long delay in receiving HCMM data (see 5.) and the time-shift of the official start of the HCM-025 Investigation, the present report covers the "TELLUS First Development Phase" which goes somewhat beyond the launch date.
During this phase research was aimed at providing the different co-investigators with the necessary tools for solving the problems connected with the future HCMM data interpretation.

Depending on the principal subjects of investigation a number of problems were considered, depending on their importance mainly in respect to the methodological aspects and on the possibility of tackling them with the available technical means.

The principal effort was devoted to determine the methodologies in ground measurements, airborne survey and in data processing and interpretation. Priority was given to setting up mathematical models and visual interpretation techniques of satellite data and to problems of data handling such as geometric corrections and superposition of night-and-day aircraft data.

6.2. Evaporation and Soil Moisture

6.2.1. The approach adopted

6.2.1.1. Methodological aspects

A two-way approach has been adopted:

1. A first approach consists of the visual interpretation of the HCMM-images (originals or transformed).
   The method may be described as an analog-deductive interpretation procedure, final products being hydro-geological maps.

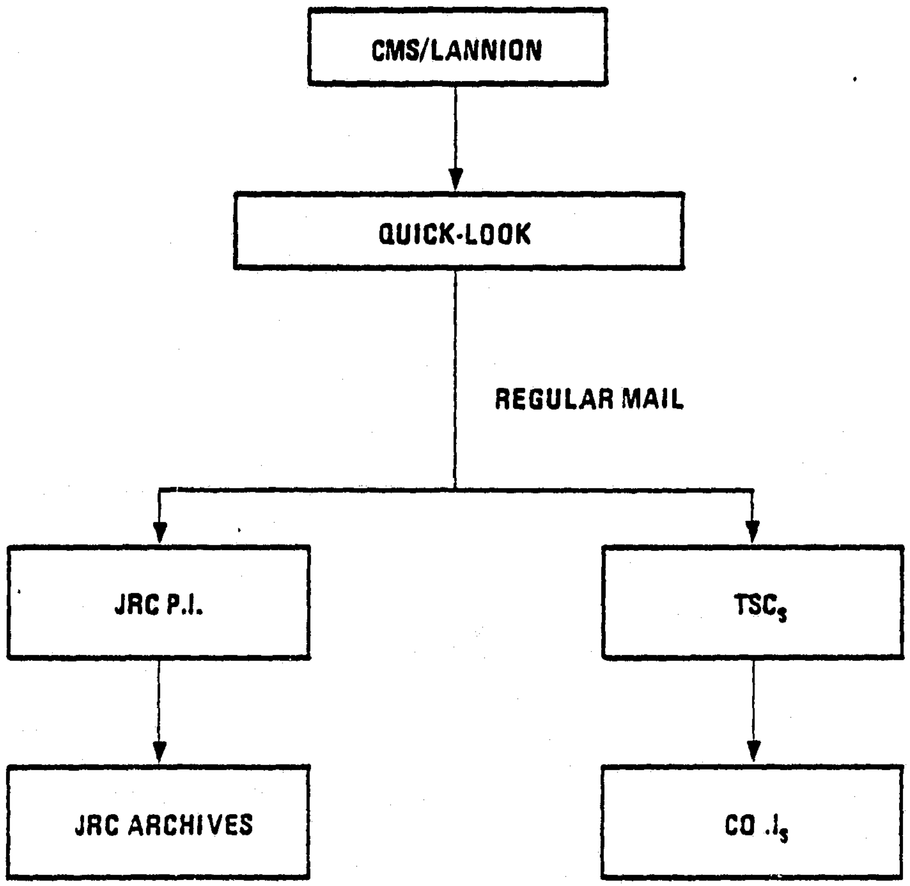


FIG. 3 : FLOW DIAGRAM OF HCMM DATA DISTRIBUTION FROM LANNION

2. The second one involves a mathematical modelling procedure.
   It employs digital models the parameters of which are obtained from air-and-space platforms (aircraft and/or HCMM satellite) and ground-based instrumentation. In fact, one method of estimating evapotranspiration and soil moisture content is to use a model of the energy balance of the soil surface and of the atmospheric boundary layer. Such a model may be written in a form that most of the input data used are routinely observed and it may be adapted so that remotely-sensed measurements may be included.
   Thus it may be considered a mathematical-experimental interpretation approach. Final products are thematic maps (evapotranspiration, soil moisture, etc.).

   This approach was chosen as the most suitable one for our investigation. In fact, synoptic estimation by remote sensing of evapotranspiration and soil moisture is an important research subject of quite general interest not only among TELLUS Co-Investigators but also more extensively in Europe.

Finding empirical correlation only between surface temperature and soil moisture and ET would perhaps suffice on a local basis but would not permit a comparative study of results obtained under the various European conditions.

Therefore it was decided to gain a deeper understanding of the processes relating evapotranspiration and soil moisture with other ground parameters and remotely sensed signals. The approach chosen was:

1. to obtain an exhaustive phenomenologic description by a mathematical model,

2. to test the model for a number of field conditions.

In this way, after confirmation that the mathematical expressions correctly describe the processes involved, one can verify the importance of the various parameters and try to simplify the model accordingly. One may also attempt to extend the model from the punctual (local) condition to a more extended (regional) one. A full sensitivity analysis may also be applied to the model in order to identify the parameters which may be neglected, in relation to the reciprocal importance, the accuracy requested by the output and the nominal error of the remotely sensed signals (aircraft and/or satellite).
At this point, the different field tested mathematical expressions may be compared with the empirical relations obtained for the same field conditions employing regression analysis or similar techniques. This will be in favour of a better understanding of the processes involved.

We are conscious that the agricultural land structure in Europe is rather fragmented and small as compared to the HCMM resolution of 0.6x0.6 km.

The complex pattern of geomorphology and land use on the European continent poses the problem of the meaning of HCMM pixels under these conditions. The thermal signal from a surface of 0.6x0.6 km will in many cases be the result of the thermal emission from a number of small patches, each of them having different emission properties.

An attempt is being made of "scaling up" the partial informations of the small pixels composing a HCMM pixel to the overall 0.6x0.6 km information. This technique is based on the comparison of groups of pixels of an aircraft flight taken at a given altitude with groups of pixels of an aircraft flight taken at a higher altitude over the same area. Through successive comparisons of increasing area between pixels corresponding to flights at higher altitudes one can arrive to the final comparison with a satellite pixel.

6.2.1.2 Visual interpretation

Visual interpretation of HCMM images was carried out using current methods of photointerpretation. A flowchart of the method is presented in Fig. 4 .
The instrumentation employed consisted of stereo plotter, densitometer, analoge image analyser and an additive colour viewer. Maps, LANDSAT and Skylab images were used in the process and their relative effectiveness in identifying geomorphologic and topographic features was compared.

A preliminary analysis of the first thermal test image from Cheasapeak Bay (May 11, 1978, 14.03 h) showed the superiority of the HCMM thermal image over LANDSAT images in detecting alluvial plains, marshes, low lying areas and relict river beds. LANDSAT was superior in identifying main water courses and water pollution plumes. A TELLUS Newsletter on this work is in preparation.

A further physiographic analysis was carried out for the Po Valley using VIS, DIR and NIR images as well as images from LANDSAT (bands 4, 5 and 7) and Skylab (band 7) (Barisano, 1). Regarding the hydrologic aspects, only the DIR image permitted to identify the upwelling zones of aquifers (moisture in depth), while the NIR image allowed localization of surface moisture. To a lesser degree the NIR image could be used to differentiate rock formations.

A comparison of the usefulness of HCMM, LANDSAT and Skylab data for identifying geomorphologic and topographic features in the Po Valley is given in Table. 9 .

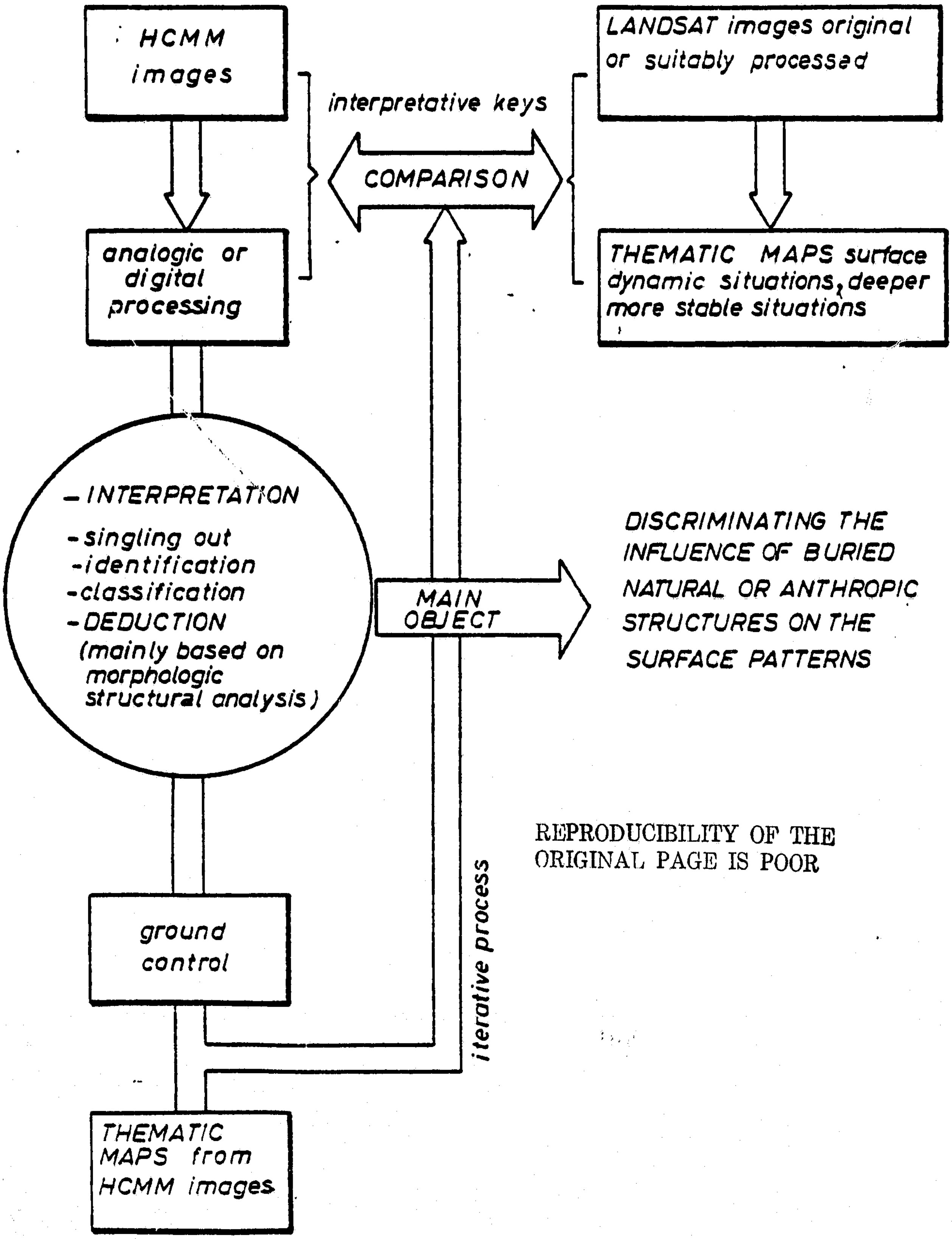


Figure 4 Flowchart of the visual interpretation process

One should note the superiority of HCMM thermal images in identifying ground water, alluvial plains, moraines and ancient river beds. No general value should be attributed to the classification in Table 9. as it is limited to the case actually treated.

Table 9. Comparative evaluation of HCMM, LANDSAT and Skylab images for identifying geomorphologic and topographic features in the Po Valley

Object	HCMM	LANDSAT-2 and Skylab
Geomorphologic		
River beds	++	+++
Lakes	+++	+++
Alluvial plains	+++	++
Ancient river beds	+++	++
Ancient meanders	+++	++
Moraines	+++	+
Surface moisture	+++ (NIR, VIS) + (DIR)	+++
Ground water	++ (NIR)	-
Topographic		
Towns	++++	++++
Roads and railroads	++	+++

Identification was:

very good	++++
good	+++
medium	++
poor	+
impossible	-

6.2.1.3 Mathematical modelling

6.2.1.3.1 General description

Two models have been developed up to now. The first one, the "TERGRA" model, developed by Soer (Soer, 2) is for use in grassland-type areas and, using one measurement of the soil surface temperature, gives estimates of the daily evaporation. The other, the "TELL-US" model, developed by EARS (EARS, 3), is for use on bare soil, and estimates both daily evaporation and thermal inertia using measurements of both day-time and night-time surface temperatures.

Both models are layered models, which require known boundary conditions at a given height in the atmospheric boundary layer and at a given depth in the soil in order to solve the equation of the energy balance of the crop-or-soil surface. The models are based on the equation of the heat diffusion in the soil

$$\frac{dT}{dT} = \frac{\lambda}{c} \frac{d^2T}{dz^2}$$

The atmosphere and the soil regime are coupled by the continuity requirement:

$$R_n + G + H + LE = 0 \qquad /20\text{-}1/$$

which is the energy balance of the soil or crop surface.

In /7-1/ R_n is the net radiation flux, G the soil heat flux, H the sensible heat flux in the atmospheric boundary layer and LE the latent heat flux. The equation may be solved numerically for each level z' to give a temperature profile using a finite element or finite difference method, taking the soil or crop surface temperature as the upper boundary condition, and some known temperature at a given depth in the soil as a lower boundary condition.

The net radiation flux is the difference between the incoming and outgoing short- and long-wave radiation fluxes

$$R_n = (1 - \alpha_s) R_s + (1 - \alpha_\ell) R_\ell - \varepsilon_c \sigma T_c^4 \qquad /20\text{-}2/$$

where R is the incoming short wave and R_ℓ the incoming long wave radiation, α and α_ℓ the short and long-wave soil or crop reflection coefficients ε_c the soil or crop emission coefficient, σ the Stefan Boltzmann constant, and T_c the soil-or-crop surface temperature. For long wave radiation $\varepsilon_c = 1 - \alpha_\ell$, so equation /20-2/ may be written

$$R_n = (1 - \alpha)_s R_s + \varepsilon_c (R_\ell - \sigma T_c^4) \qquad /20\text{-}3/$$

The soil heat flux G through any z = z' is related to the temperature gradient in the soil (dT/dz) and the thermal cunductivity λ, both evaluated at z':

$$G = -\lambda \frac{dT}{dz} \qquad /21\text{-}4/$$

The sensible heat flux may be estimated using a transport equation depending on the air temperature T_a, the soil or crop surface, T_c, the aerodynamic resistance, r_a and the air density ϱ and the specific heat c_p:

$$H = \varrho c_p \frac{(T_a - T_c)}{r_a} \qquad /21\text{-}5/$$

The latent heat flux may also be expressed as a transport equation:

$$LE = \frac{\varrho c_p}{\gamma} \frac{(e_a - e_s)}{r_a + r_s} \qquad /21\text{-}6/$$

where γ is the psychometric constant, e_a the water vapour pressures in the atmosphere layer, e_s the saturated water vapour pressure at temperature T_c, and r_s the stomatal diffusion resistance to water vapour transport. The quantities e_a and e_s may be estimated from T_a and T_c. Quantity r_s will be discussed in the following section on the TERGRA model.

By comparison of the above terms it may be seen that the components of the energy balance may be expressed as functions of the air temperature, the temperature at a given depth in the soil and the soil surface temperature, as well as of the incoming radiation and the aerodynamic and stomatal resistances. As said in 6.2.1.1, most of these variables are being measured or may be estimated from routine observations. The exception is the crop or soil surface temperature, T_c, which is not routinely measured except at a few sites.
This measurement has to be supplied by HCMM, by an airborne scanner or by ground based infrared thermometers.

- Application of the model

The initial estimate of the surface temperature T_c will probably not satisfy the continuity requirement of the energy balance equation, because of the simplifications necessary to estimate a number of parameters such as r_a or r_s. Therefore, it is necessary to use an iterative numerical optimization technique to ensure that the condition of the energy balance equation is satisfied. This procedure may be adopted to give estimates of the surface temperature T_c corresponding to every time step of a set of routine measurements of air temperature, wet bulb temperature, wind speed and incoming short and long wave radiation.

As said before, the soil or crop surface temperature measurements are not made routinely. As thermal emission measurements they are made instantaneously by the radiometer mounted on the aircraft or on the HCMM spacecraft. It is possible to compare them with those estimated from the model and then to adjust the parameters of the model until the estimated surface temperatures are the same as the measured surface temperatures at the same time. These parameters such as the aerodynamic resistance r_a and the thermal heat capacity of the soil c_v may then be used to give more accurate estimates of daily evapotranspiration or soil moisture.

6.2.1.3.2. The TERGRA model

- Specific motivation

In Western Europe potential evapotranspiration of crops generally exceeds effective rainfall in spring and early summer. Under these circumstances, when the available moisture in the root zone is exhausted and capillary rise from the groundwater table does not succeed in supplying sufficient water to achieve the potential evapotranspiration rate, evapotranspiration will be reduced. This results in a lower crop growth and crop production. In such conditions, simultaneously with the decrease in evapotranspiration, the temperature of the crop surface will increase. As distinct physical relation between the surface temperature and the evapotranspiration rate of a crop does exist, it is possible to calculate actual evapotranspiration from the crop surface temperature. Subsequently, the moisture condition of the soil can be estimated from the evapotranspiration rate.

Up to now, owing to the high cost of measuring actual evapotranspiration, conventional evapotranspiration measurements were limited to small hydrologically uniform areas. The use of remotely sensed crop surface temperatures eliminates the need of intensive field measurements and offers the possibility to obtain regional evapotranspiration estimates, making water balance analysis for large areas more feasible. For specific regions, crop production as correlated with the actual crop transpiration rate could be estimated. The extremely dry summer of 1976 affecting large parts of Western Europe emphasized once more the importance of having such large-area information.

- Model description

The TERGRA model was developed as an aid for the interpretation of infrared line scanning images of cropped surfaces, with particular emphasis on grassland. The model simulates, under specific meteorological conditions and for different situations of soil moisture, the daily behaviour of crop temperatures and energy balance components. Boundary conditions are the temperature and soil water potential at a reference level in the soil, and the temperature and water vapour pressure at a reference level in the atmosphere.

- Water and heat flow in the soil-plant-atmosphere continuum

Water and heat transport in the atmosphere are mainly passive transport processes, governed both by momentum exchange. Relevant phenomena are expressed by terms /21-5/ and /21-6/.

Under evaporative conditions, water flows from the root zone through the root epidermis, the plant hydraulic system and the stomata to the atmosphere. In the root zone, water flow meets a resistance depending on soil water pressure. The resistances in root epidermis and plant hydraulic system are taken to be constant in this study. The stomatal resistance depends on the opening of the stomata which controls the release of water to the atmosphere.

While water flow is mainly governed by plant physiological factors, heat flow is more passive, depending on the plant's ability to evaporate. Though the heat flow resistances in soil, canopy and atmosphere are variable, they do not influence the heat flow considerably.
Fig. 5 shows the model's physical diagram.

- Parameters r_a and r_s

The model uses a Businger-Dyer approach to estimate the turbulent diffusion resistance r_a which is given as a function of wind velocity, the stability of the atmospheric boundary layer just above the surface, and the nature of the surface. Different terms are applied under stable, neutral and unstable atmospheric conditions.

Crop resistance can simply take into account stomatal resistance r_s.
In fact, cuticular resistance is at least one order of magnitude higher than r_s and flow through the cuticula may be neglected.
Stomatal resistance r_s is a result of closing of the stomata. It is caused by decreasing water turgor pressure in the guard-cells surrounding the stomata, which is mainly influenced by leaf water pressure ψ_l and incoming shortwave radiation R_s. Thus closure of stomata occurs when R_s is low, i.e. during night.
The stomatal resistance r_s is found from a set of empirical relations with crop height, the short wave radiation and the leaf-water pressure.

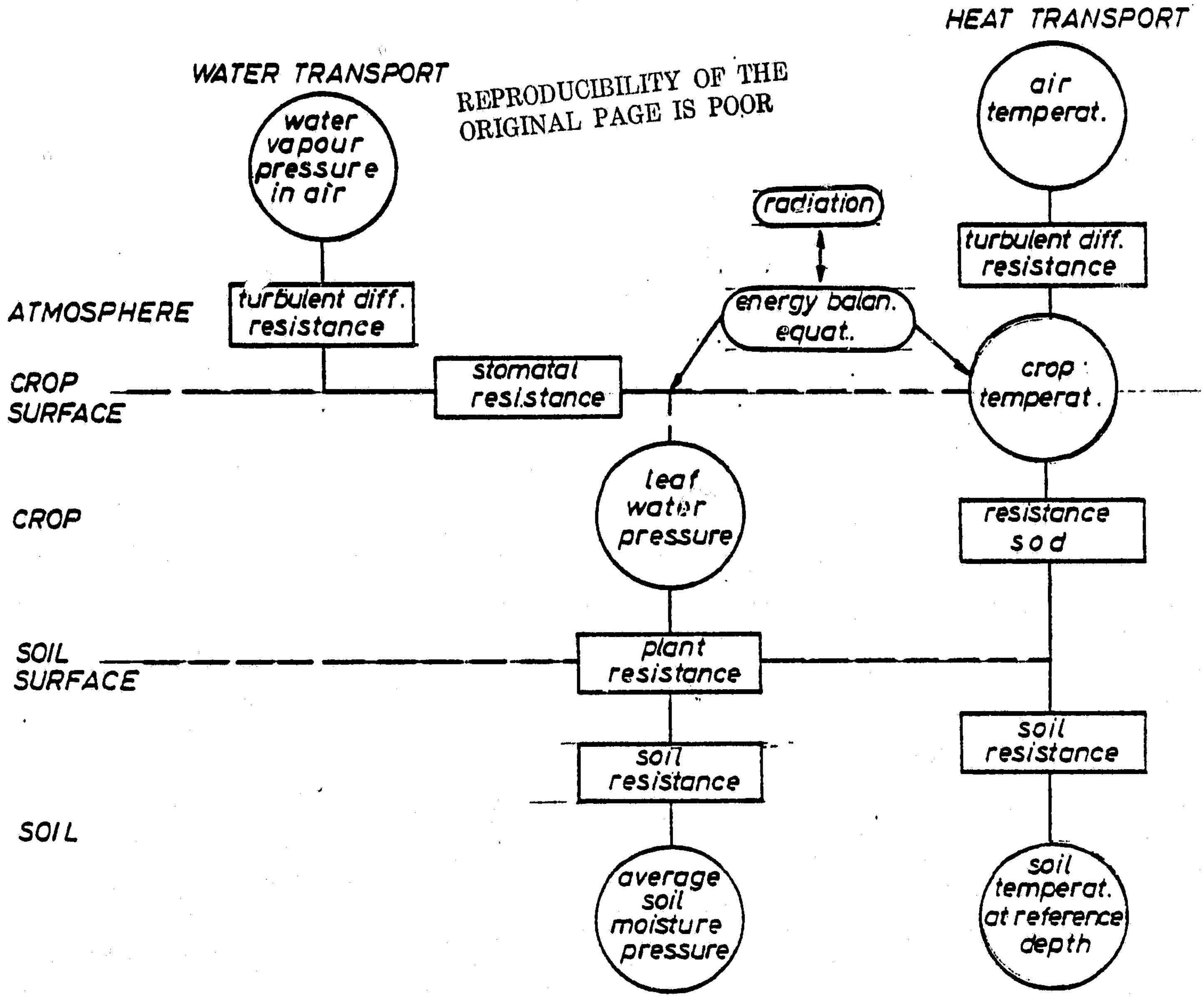


Figure 5 Physical model of TERGRA

- The numerical algorithm

Fig. 6 shows the flow diagram of the algorithm. The soil heat flux is estimated using an explicit finite difference method with the spacings between each node being equal. The iteration of the surface temperature is also simple, the surface temperature being altered by successive small amounts until an energy balance has been achieved. This approach is satisfactory where the components of the energy balance are not changing rapidly between successive time steps, so that the initial estimate of the surface temperature (i.e. the temperature estimated from the previous time step) is close to the final estimate.

As noted above, the TERGRA model directly estimates the daily evaporation. Changes in the soil moisture may also be estimated from the evapotranspiration flux, E, estimated by the term /21-6/.

- Obtaining soil moisture

Given the evaporation, soil moisture is obtained by a set of relationships as follows. For grassland, E may be expressed as

$$E = \frac{1}{g} \frac{\psi_1 - \psi_s}{r_{plant} + r_{soil}} \qquad /25\text{-}1/$$

where ψ_1 is the leaf water pressure, ψ_s the soil water pressure, r_{plant} the plant resistance for water transport, and r_{soil} the soil hydraulic resistance. Given estimates of ψ_1, and the resistances r_{plant} and r_{soil}, ψ_s may be estimated.

These may be found using empirical relationships with other variables and then ψ_s may be related to the volumetric water content, Θ, by

$$\psi_t^{-m} = \frac{S - S_r}{1 - S_r} \qquad /25\text{-}2/$$

where S is the saturation, defined as Θ/Θ_S (Θ_S being the moisture content at saturation). S_r is the rest saturation, m is a pore size distribution factor, and ψ_t is a re-scaled soil water pressure; equal to ψ_S/ψ_a, where ψ_a is the air entry value.

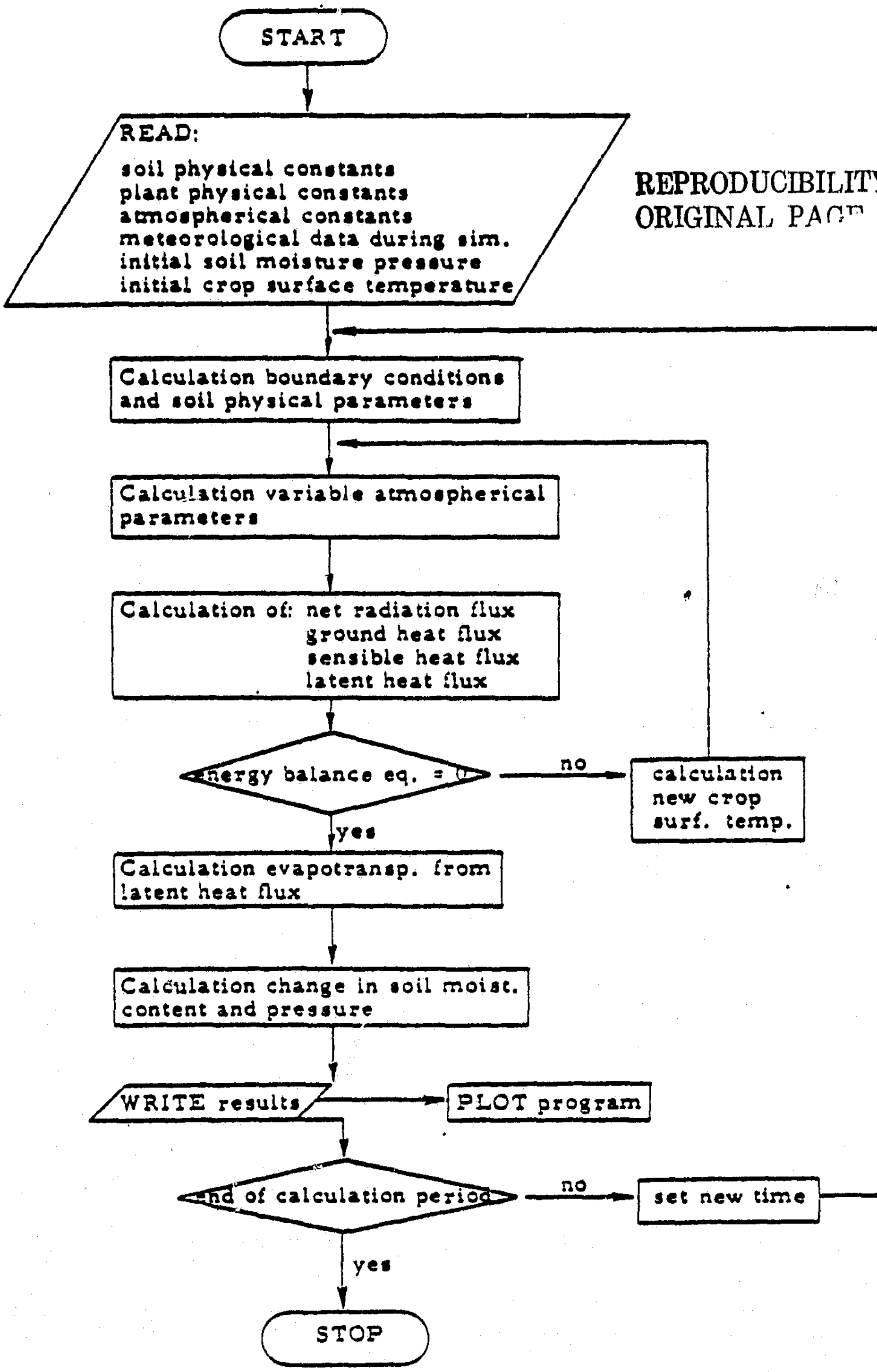


FIG. 6: FLOW DIAGRAM OF THE TERGRA MODEL

6.2.1.3.3. The TELL-US model

Introduction

In TELL-US an algorithm has been developed to convert remotely sensed day and night temperatures of bare and scarcely vegetated areas into parameters relevant to daily evapotranspiration and soil moisture.

Such an interpretation routine calls for a process which is the reverse of temperature simulation. For this purpose, and mainly in the U.S., methods have been worked out to calculate the thermal inertia of the soil from the difference between the day and the night temperature to be obtained by means of HCMM /4, 5, 6/. This approach has been discussed /7/ which is limited to cases of known or negligible small evaporation. Moreover, in this approach only one data point, i.e. the D/N temperature difference is used, while two data, the D and N temperatures are available. Therefore, in principle, two unknowns could be determined.

This has been achieved by means of the TELL-US algorithm. It uses two separate estimates of surface temperature, ideally at the times of maximum and minimum thermal emission (about 14.000 and 02.00 local time) and so allows two unknowns to be estimated directly, without the need to employ empirical relationships such as those used in TERGRA to derive one of these unknowns. In this model, thermal inertia and evaporation are estimated; an experimentally-derived relationship may be found between thermal inertia and soil moisture.

While the general structure of the model is similar to that used in TERGRA there are some differences. The soil heat flux is again found using an explicit finite difference method, but in TELL-US the spacing between nodes is allowed to increase downwards. The iteration at each time step is also rather faster than for TERGRA and it converges rapidly.

The TELL-US system does contain only two unknowns: the surface relative humidity, h, and the thermal intertia $p = (\lambda c_v)^{1/2}$).

The algorithm

The algorithm consists of a main program and a set of sub-programs simulating the daily course of the surface temperature. The main program compares the simulated D and N temperatures with the remotely sensed temperatures. It produces suitable look-up tables.
A detailed description of the model is given in / 3 /.

In Table 10 the essential input data are reviewed. They have been regrouped into "field" and "regional" data. The field data must be specified for every ground plot to be interpreted. When it is deemed valid, the regional data may be obtained from the nearest weather station.

Acquisition	Data	Spatial resolution
Satellite or aircraft	Day surface temperature (maximum) Night surface temperature (minimum) Albedo	Pixel
Topographic or land use maps	Surface aerodynamic roughness Slope direction and dip	Field
Estimates	Sub-surface temperature Initial surface temperature	Sub-region or flight strip
Weather station, every hour	Air specific humidity Air temperature Wind speed Solar irradiance	

Table 10 Input data for the TELL-US algorithm.

Slope direction and slope dip have to be estimated from topographical maps. The surface temperatures and the albedo may be obtained by means of the HCMM satellite or an airborne scanner.

Test of the algorithm

In April 1978, the TELL-US algorithm has been tested on data from a field experiment of the USWCL at Phoenix, Arizona /8 /. Data measured 2.6 and 14 days after irrigation have been used. The soil temperature measured at 1 mm depth was taken to be a good approximation of the surface temperature. The soil moisture profiles were measured gravimetrically. The total daily evaporation was measured by a weighing lysimeter.

Comparisons with the values determined by means of the TELL-US algorithm are reported in /9 /. The agreement between measured and calculated soil moisture is good: it goes from the full coincidence (2 days after irrigation) to an average moisture content of the top of 8 cm of the soil (14 days after irrigation).
Comparison for total daily evaporation is not yet satisfactory as, except for the initial drying stage, the algorithm tends to underestimate evaporation. The reason for this tendency lies in the assumption of a constant surface relative humidity which causes excessive condensation to be simulated for the night.

6.2.1.3.4 Regional evapotranspiration

The knowledge of actual evapotranspiration (ET) on a regional scale (e.g. 10 to 10,000 km^2) would be of considerable interest in climatology, hydrology and agriculture. In particular, its effect on the local climate, its role as a major component in the regional water balance and its effect on crop yields could be better evaluated. Therefore, three approaches specific for the use of HCMM data in estimating regional ET have been considered (Seguin, 10/.

1. Correlating day/night differences in surface temperature with ET
2. Differential thermal approach. This approach is based on the relationship between the difference in vapour flux between two sufaces and the difference in their surface temperatures, provided the surfaces are similar except for their water regime. Soil heat flux and albedo have to be assumed equal for the two surfaces.
   In this case, using equation /21.9 / the evapotranspiration

$$ET_1 = ET_2 + (4\sigma T_a^3 + Cp\ h)\ (T_{s1} - T_{s2}) \qquad /29\text{-}1/$$

   from a surface 1, ET_1, can be calculated with the aid of a known evapotranspiration from a reference surface, ET_2, and the difference in their surface temperatures, $T_{s1} - T_{s2}$ (Itier and Perrier, 11).

3. Combined aerodynamic-energy balance approach. This method is essentially the same one as used in the TERGRA model. It consists in calculating the sensible heat flux by the aerodynamic equation relating flux to the difference in air and crop surface temperature. The latent heat flux, the evapotranspiration ET, is then derived from the energy balance.

6.2.2 Field operations

Field operations carried out in the pre-launch period had the purpose of testing the algorithms to be used for the interpretation of HCMM data. At the same time, the thermal infrared data produced served to prepare the necessary data processing routines and acquainted the co-investigators with the handling and interpretation of this type of data.

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.

6.2.2.1 Flight experiments

Three flight experiments took place in the pre-launch phase, in the Netherlands, the United Kingdom and in France. While the Dutch flights were organized by the National Institutes, the U.K. and French flights were Joint Flight Experiments (JFE) with the participation of both National Institutes and the Joint Research Centre.

6.2.2.1.1 The Netherlands (ICW, KNMI)

Flights with an airborne MSS having 10 channels between 0.38 and 1.1 μm and one thermal infrared channel from 8-14 μm were performed over two areas. The first area, located in the Lopikerwaard ($51^{o}38'$ N, $4^{o}55'$ E) consisted mainly of grassland on clay soil. The second area was situated in the Ijssel Lake Polder ($50^{o}13'$ N, $7^{o}3'$ E) and was occupied by various agricultural crops, especially wheat, sugar beets and potatoes. The soil was a silty clay.

Flight altitude was 1200 m resulting in 2.5x3 m resolution elements on the ground. The flights were carried out at the maximum of the daily temperature amplitude between 12 and 14 hrs solar time. The dates were May 15, June 14 and August 31, 1977 for Lopikerwaard and May 17 and June 14, 1977 for the Ijssel Lake Polder.

Purpose of the flights was testing of the TERGRA model for the evaluation of ET and soil moisture from crop surface temperatures.

Details of the operation, as well as a description of the instrumentation on the ground is given in TELLUS Newsletter 2 (Annex II).

Results and conclusions: On thermal scanner images the relation scan angle/sun angle influenced considerably the temperature measured. For grassland, as well as for wheat, calculation of evapotranspiration from remotely sensed surface temperatures only was unreliable. Crop (wheat) temperatures simulated with the TERGRA model were higher by a few degrees than measured temperatures.

More research should be carried out on the physical interpretation of remotely sensed crop temperatures. In the meantime, a thermal differential approach (section 6.2.1.3.4) should eventually be used.

6.2.2.1.2 France (INRA/ST/SB, JRC)

A Joint Flight Experiment (JFE/France) was carried out on Sept. 30 , 1977 on the French test site of the Beauce along a flight axis of 20 km centered on a point south of Chartres (48°13'49" N, 1°36'01 E). The flight axis crossed a mixed agricultural area covered mainly by corn, sugar beets, stubble and bare soil.

One experimental plot on wheat stubble was equipped for measurements of the energy balance. Surface temperatures were measured on the ground with a mobile PRT-5 infrared thermometer.

Two flights at 1700 m altitude were carried out along the same axis, the night flight at 00.52 hrs and the consecutive day flight at 13.05 hrs local time. On-board instrumentation consisted of a 10-channel Daedalus MSS, a Daedalus thermal scanner 8-14 µm, a PRT-5 infrared radiometer and a 4-channel SAT thermal scanner.

The purpose of the JFE was an investigation of the surface temperature distribution in various types of vegetation. Details of the operation including a description of the instrumentation are given in Annex XI.

Results and conclusions: Surface temperature variations were found to be larger inside one crop than between various fields of the same crop. During the day, meteorological data needed for the interpretation of remotely sensed surface temperatures should be obtained at exactly the same time as the surface temperature.

A simple model containing three resistances will be used to calculate ET. In this model, surface temperatures from HCMM should serve to correct the values of stomatal resistance.

Thermal data from this flight was used to simulate HCMM resolution over a mixed agricultural area. The result of this simulation is reported in TELLUS Newsletter 1 (Annex I).

6.2.2.1.3 United Kingdom (IHW, UL/DG, UR/DG, JRC)

A Joint Flight Experiment (JFE/UK) was carried out on Sept. 13 on the U.K. test site along two flight axes of 10 km each. The first flight axis was over the Grendon-Underwood Experimental Catchment (1° W, 51°53' N) composed of gently sloping land with fields of up to 15 ha.

The second flight axis passed over the Newbury area (1°44' W, 51°20' N) with fields up to 12 ha.

Soils on the two sites ranged from brown calcareous soils and surface water gley to clays. Land use was cropland (cereals) and grassland with some forest and market gardening.

Grassland and bare soil were instrumented on the Grendon site, measuring points on arable soil, grassland and bare soil were established on the Newbury site. A detailed description of the flight and of the instrumentation on the ground is given in Annex XI.

Two consecutive flights at an altitude of 1000 m were carried out along the same flight path: A night flight between 04.25 and 05.15 GMT and a day flight between 12.45 and 13.35 GMT. On-board instrumentation consisted of a Daedalus DS-1250 MSS with a thermal channel from 8-14 μm a Barnes PRT-5 infrared thermometer coupled to a Hasselblad camera and a RC-883 camera.

The purpose of the JFE was acquiring experience in the interpretation of thermal imagery of agricultural land surfaces. In particular, data should be obtained to test the algorithms (TERGRA and TELL-US) for the evaluation of soil moisture and evapo-transpiration from remotely sensed surface temperatures.

<u>Results and conclusions</u>: The thermal and visible-IRR airborne MSS data obtained during the campaign were of excellent quality. They were used to develop data processing routines like geometric corrections and the superposition of day and night images. They also served as data for speeding up the execution of the TELL-US algorithm and for testing the sensitivity of both the TERGRA and TELL-US model.

An important part of this work has been carried out at the JRC-Ispra Image Processing Laboratory which disposes of the following installations:

- DEC PDP-11/70 with floating point processor and 512 KB core memory,
- two disk units of 67 MB each,
- one dual density 1800/1600 BPI tape unit,
- card reader, line printer, teletype and video terminals,
- S.E.P. VIZIR high-precision, high-speed laser image recording unit (up to 30,000x30,000 points in 64 grey levels with resolutions of 13.5 μ and 40.5 μ),

- DEC PDP-11/05 with 56 KB core memory,
- four logical disk units of 2.5 MB each,
- video terminal and line printer,
- COMTAL image display unit with 3 image memories of 512x512 bytes each, contrast function and pseudo-colour tables, trackball/target, 3 graphic overlay memories.

The PDP-11 computers are connected through a 1 Mbaud communication link.

TELL-US model. Soil moisture and evaporation was mapped by processing in the TELL-US model pixel by pixel values of day and night surface temperature and albedo together with ground data (e.g. surface roughness) varying field by field and meteorologic data (e.g. solar radiance, windspeed, air temperature) valid for the whole flight strip. To this purpose, a tabulated version of the algorithm was prepared which uses multiple interpolations within tables to reduce processing time to a few msec per pixel. The scanner data were first corrected for scan angle effect and for geometry to permit superposition of night thermal data on day visible and thermal data. Details of the methods can be found in Annex XV.

Three types of thematic maps were obtained representing thermal inertia, soil moisture and cumulative daily evaporation of bare or vegetated areas (bare soil, burnt and unburnt stubble, stubble with some green shoots). Each of the three parameters had five to seven classes of magnitude and was presented with a ground resolution of 2.5x2.5 m, equal to that of the scanner data.

It could be confirmed, that a detailed mapping of thermal inertia, soil moisture and cumulative daily evaporation was possible using a complex model like TELL-US. Obviously, the data processing scheme developed is independent of the intrinsic performance of the model and each further improvement of the latter will bring some corresponding improvement of the thematic maps produced.

The comparison with measured soil moisture values suffers from experimental uncertainties, but it seems to indicate a tendency to underestimate soil moisture content. Direct measurements of evaporation were not available at Grendon, but independent calculations of ET agree within 10% with the values obtained by TELL-US. In inhomogeneous areas, like burnt stubble, where temperature, albedo and surface roughness vary considerably in space, these variations tend partially to mask the smoother evolution of moisture and evaporation.

An analysis of the sensitivity of the TELL-US model to various input parameters and to the value of the soil heat capacity used in the model was presented in TELLUS NEWSLETTER 8 (Annex VIII). In calm air, as often found at night, the variations in air temperature due to topography and ground-cover may have an important influence on the thermal inertia calculated with the TELL-US model.

TERGRA model. A sensitivity analysis of the model carried out for the grassland site at Grendon showed the model not to be sensitive to soil parameters at the soil moisture range found on the site (Annex III).

Cumulative daily evapotranspiration agreed to within 10% with ET calculated from Bowen ratio measurements on the Newbury site. The same agreement was found between calculated and measured soil moisture on grassland.

Spectral reflectance. The spectral reflectance in the four Landsat bands was measured on the ground on four surfaces during the flight. The surfaces were bare soil, stubble, grassland and burnt stubble. These reflectances were compared with the airborne MSS measurements.

At lower wavelengths good agreement was found between airborne and ground measured reflectance factors. At higher wavelengths, especially on grassland, there was an increasing discrepancy between the two measurements. A systematic error in the calibration of the airborne multispectral scanner seems to be largely responsible for this discrepancy. Details are given in Annex IX.

6.2.2.2 Continuous field measurements

These measurements were carried out to obtain data sets over long time periods permitting the comparison between measured evapotranspiration and evapotranspiration calculated from remotely sensed surface temperatures. The results from two measurement campaigns, Italy (Perugia) and France (Avignon) are reported.

6.2.2.2.1 Italy (ISNP, JRC)

From July 13 to September 1, 1977 measurements were carried out on an experimental farm near Città di Castello, Perugia (43°27' N, 12°15' E). Two grass plots, about 0.75 ha each, were established. One of the plots was kept dry, the second one was irrigated by sprinkling.

The surface temperature and the reflectance in the four LANDSAT bands was measured from a 5-m tower on each plot using a PRT-5 infrared thermometer and an EXOTECH-100A radiometer.

Net radiation, albedo, wind speed and direction, dry and wet bulb temperature, air pressure, soil heat flux and soil temperature were also recorded at 30-min intervals on both plots.

The summer of 1977 being exceptionally wet in central Italy, no "dry" plot could be established.
Data from one of the plots covering a six day period in August were used in the TERGRA model to calculate evapotranspiration and surface temperature. These calculations were compared with measured

During the day, there was good agreement between simulated and measured surface temperatures, with a tendency for simulated crop temperatures to be lower than the measured ones in the morning and higher in the afternoon.

At night, and for low windspeeds, simulated surface temperatures were too low and there was no agreement with measured ones.
These differences being observed at night when evapotranspiration has a very small or zero value, no significant effect on the calculated evapotranspiration could be observed.
From a theoretical point of view, the term describing sensible heat flux in the TERGRA model could be improved by including free convection, though this modification would be of small practical consequences.

6.2.2.2.2 France (INRA/CRASE/SE)

Measurements similar to the ones in Italy were carried out in the period July 15 to September 20, 1977 at an experimental field near Avignon-Montfavet (43°55' N, 4°51' E). A field of short grass (about 70x200 m) was divided into two plots. One plot was kept dry, the second plot was irrigated by sprinkling.

Global, reflected and atmospheric long-wave radiation as well as wind velocity were measured with one set of instruments for both plots.
At the centre of each plot the following measurements were carried out: net radiation, soil heat flux, Bowen ratio and surface temperature.
The surface temperature was measured with a Heiman KT-24 infrared thermometer.

These measurements were recorded with a 1-min scanning interval on a data system integrating hourly mean values.

Data from the period July 15 - August 31 were used to evaluate the three methods for calculating regional evapotranspiration described in Section 6.2.1.3.4.

- Day/night surface temperature differences, if available every 8 days (as most optimistically by HCMM), could hardly be used to detect water availability under the conditions of the test site. This statement would be less firm for daily values.

- No evaluation could be made of the differential thermal approach due to the wet summer which suppressed any significant differences between the wet and dry plots.

- The combined aerodynamic-energy balance approach gave a fairly good agreement with ET values, hourly as well as daily, calculated with the Bowen ratio method.

In 1978, the continuous measurements were transferred to dry and wet plots in the Crau compatible with HCMM resolution.
Details of the 1977 campaign and of the planned activity for 1978 are given in Annex X.

6.3 Heat Budget

6.3.1 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 effect of different land use patterns (open fields, fields with hedges) on a regional heat budget, the localization of frost prone areas and the correlation of thermal and other characteristics of land surfaces and the occurance of hail storms.

6.3.1.1 The influence of tree hedges on the surface energy budget (INRA/ST/SAP)

The present work is carried out by INRA at the French test site in Bretagne where significant changes in the mesoclimate have occurred due to the restructuration of land. In this process the characteristic tree hedges bordening fields (bocage) were cut and embankments were levelled.

Two contiguous test sites of 1100 ha each, one with hedges and one without, were investigated by day and night aerial thermography. Areas with hedges seem to warm up and cool more rapidly than open areas.

A simulation of HCMM resolution showed that at night the temperature classes identified in airborne images can be found back at HCMM resolution. This is true to a much lesser degree for daytime images.
The most significant time for night thermography in this area is before midnight, while the night pass of HCMM seems to be less favourable.
According to the simulation, thermal inertia was not suited for the characterization of the open and hedged areas.
Details of this study can be found in Annex IV. The results of the simulation will be compared wtih HCMM data when this will be available.

6.3.1.2 Hail storms (UCEA, IGA)

It is extremely difficult to localize hail storms in advance. At best, a forecast and warning can be given for an area of a few millions of hectars, while a big storm covers hardly more than 50,000 ha. As a result

the installation of preventive systems against hail are extremely costly and complex.
The present research is being carried out by UCEA in collaboration with IGA in order to correlate the beginning of hail storms with thermal, hydrologic and topographic characteristics of land surfaces. It is assumed that hail storms are formed by spatial temperature differences on the ground, as well as by evaporation from vegetation and soil and by atmospheric turbulences (Annex XVI).

A attempt is being made:

1) to spot the birth zones of thunder and hail storms, paying special attention to aspects of agricultural planning;

2) to obtain a localized forecasting of hailstorms.

Thermal maps obtained by satellite are the only source of information available on a mesoscale basis (some 100 km^2) to localize the "heat island", which are among the main factors originating storms. Variations of thermal inertia inducing thermal differences many hours before storms are also very important and may be singled out.

The HCMM satellite presents favourable characteristics for this investigation, on condition that suitable time series of thermal scenes would be available to co-investigators.

The study area chosen by UCEA is within TS No. 3 . The research has started but very few suitable scenes have been received so far from GSFC.

Use of TIROS-N and NOAA imagery is also foreseen in this context.

6.3.1.3 Localization of frost prone areas (UF/IG)

On the German test site near Freiburg work on this subject was carried out by UF/IG using airborne night thermal imagery. The investigation was carried out on a subregional scale (100 km^2), a local scale (1 km^2) and on the scale of a single terrace (0.01 km^2). The purpose of the investigation was to delimit vineyard sites in frost prone areas.

On a subregional scale, thermal scanner data from an altitude of 3600 m permitted to distinguish the vineyard slopes, warmer by 2-3° than the cold plain.

On a local scale, the airborne thermal imagery was digitally enlarged. By mobile measurements of air temperature on 10 clear nights the limits of cold surface temperatures and air temperatures in the valley bottom could be shown to coincide rather well.

Flight altitude had to be lowered to 1000-2000 m above ground level to obtain results significant on the scale of one vineyard. With thermal data from 750 m hight it was possible to show that large terraces, built for the use of mechanized equipment, formed cold traps and were unsuited from a micro-climatologic point of view.

Details of this investigation are given in Annex VI.

6.3.2 Anthropogenic heat release (UF/IG)

The long delay in the distribution of HCMM data and the high percentage of cloud cover of the images of the German test site received, have seriously delayed work on this subject.

In the preparatory phase, work was carried out by UF/IG in Germany on wind-induced micro-climatic differences detected from thermal scanner data. The study treated a mixed urban-rural area. Details are given in Annex V.

6.4 Working Groups

Three working groups (WG) were formed in the project to deal with its various scientific aspects. Each of the six groups of Co-Investigators is represented by one member in each working group. Additional scientists from inside and outside the project are invited to attend the meetings of the WG which are held once or twice yearly.

The working groups cover the following subjects:

WG I : Planning of flight experiments. This group was responsible for elaborating the general outlines of the Joint Flight Experiments. It ceased its activity with the execution of the first JFE.

WG II : Energy balance, soil moisture and evapo-transpiration. Modelling and measurements. The group treats the theoretical basis of the project and proposes the direction for further development of models and instrumentation. It discusses the results of measurement campaigns and is active in the planning of such campaigns.

WG III : Data processing and atmospheric corrections. All questions of data handling are treated by this group, such as distribution of computer programs, standardization of formats, streamlining of computer models.

6.5 Conclusions

Due to the long delay in the distribution of HCMM data and the rather haphazard way these data are being delivered, the present report refers mainly to work carried out in the pre-launch phase.

The only interpretation carried out on HCMM images was a visual one. Both VIS, DIR and NIR were found to be of good quality and well suited for the identification of geomorphologic features. Only relative gray tones were employed in this analysis and no use of absolute temperatures was attempted.

The pre-launch aircraft program and the measurement campaigns produced a number of useful results, especially in the form of algorithms leading from thermal images to maps of soil moisture and evapotranspiration. Data processing routines such as geometric corrections and superposition of night and day aircraft data have been worked out.

In the next phase of the project the methods developed should be applied to the satellite data. Absolute temperature calibration will be of great importance at this stage as well as the availability of test areas compatible with the ground resolution of the satellite.

7. ANNEXES

I. TELLUS NEWSLETTER 1.
P. Boissard and Ch. Goillot. Simulation of HCMM resolution from airborne thermal scanner data.

II. TELLUS NEWSLETTER 2
G.J.A. Nieuwenhuis and W. Klaassen. Estimation of the regional evapotranspiration from remotely sensed crop surface temperatures.

III. TELLUS NEWSLETTER 3
J. Huygen and P. Reiniger. A sensitivity analysis of the TERGRA model for the conditions of the Grendon test site (JFE/UK - 1977)

IV. TELLUS NEWSLETTER 4
P. Boissard, P. Valery, P. Belluomo and Ch. Goillot
Assessing the heat budget at soil level by means of airborne thermography. Preview of HCMM capabilities.

V. TELLUS NEWSLETTER 5
W. Nubler. Wind induced microclimatic differences from thermal scanner data.

VI. TELLUS NEWSLETTER 6
W. Endlicher. Thermal imagery as a tool to delimit vineyard sites liable to cold-air damage

VII. TELLUS NEWSLETTER 7
K. Gilman. Movement of heat in soils

VIII TELLUS NEWSLETTER 8
J. Huygen and P. Reiniger. A test of the TELL-US model for the conditions of the Grendon test site (JFE/UK - 1977)

IX. TELLUS NEWSLETTER 9
G. Maracci. Comparison of spectral reflectances measured by airborne scanner and on the ground.

X. B. Seguin. Estimates of regional ET from HCMM data: Summary of 1977 experiment and final arrangements for 1978 in Southeastern France test site. WG II, Wallingford.

XI. TELLUS Project : Joint Flight Experiment UK/1977. Report No. 1. Planning and Execution.

XII. Rapport Technique. Campagne TELLUS Beauce 1977.

XIII. R.J. Gurney. The estimation of soil moisture content and actual evapotranspiration using thermal infrared remote sensing. 5th Annual Conference of the Remote Sensing Society, Durham, England, Dec. 1978

XIV. A. Rosema, J.H. Bijleveld, P. Reiniger, G. Tassone, K. Blyth and R.J. Gurney.
"TEL-US" a combined surface temperature, soil moisture and evaporation mapping approach.
12th Int. Symp. on Remote Sensing of the Environment, Manila, Philippines, April 1978

XV. J. Dejace, J. Mégier, M. Kohl, G. Maracci, P. Reiniger, G. Tassone and J. Huygen.
Mapping thermal inertia, soil moisture and evaporation from aircraft day and night thermal data.
13th Int. Symp. on Remote Sensing of the Environment, Ann Arbor, April 1979

XVI. E. Rosini and P. Caponigro.
Il telerilevamento per lo studio a mesoscala delle disuniformità termiche ed idriche del suolo: Applicazione alla previsione locale dei temporali nell'ambito del Progetto TELLUS.
XXIV Rassegna Int. Elettronica Nucleare ed Aerospaziale Roma, March - April 1977.

8. ABBREVIATIONS

AEM	Application Explorer Mission
AL	After Launch (days)
ATI	Apparent Thermal Inertia
CC	Cloud Coverage
CCT	Computer Compatible Tape
CETIS	Centre Europ. de Traitment de l'Information Scientif.
CMS Lannion	Centre d'Etude de Meteorologie Spatial de Lannion
COI	Co-Investigator
DIR	Day Infrared
DV	Day Visible
D	Day
EC	European Communities
ESA	European Space Agency
ET	Evapotranspiration
GMT	Greenwich Meridian Time
GSFC	Goddard Space Flight Center
GDTA	Groupement pour le Developpement de la Teledet. Aerospatiale
HCMM	Heat Capacity Mapping Mission
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 Geographique 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
PC	Priority Coverage
PI	Principal Investigator
PPL	Priority Processing List
QL	Quick Look
RO	Retrospective Order
SC	Spacecraft

SO	Standard Order
TD	Temperature Difference
TI	Thermal Inertia
TRK	Track
TS	Test Site
TSC	Test Site Coordinator
USWCL	U.S. Water Conservation Laboratory, Phoenise, AZ.
VIS	Visible
WG	Working Group

9. SYMBOLS

c	Soil heat capacity
c_p	Air heat capacity
e_a	Water vapour pressure in air
e_s	Saturated water vapour pressure
G	Soil heat flux
g	Gravitational acceleration
H	Sensible heat flux
h	Surface relative humidity
LE	Latent heat flux
m	Pore size distribution factor
p	Thermal inertia
R_n	Net radiation flux
r_a	Aerodynamic resistance
r_s	Stomatal resistance
S	Saturation
S_r	Rest saturation
T	Temperature
T_a	Air temperature
T_c	Crop temperature
t	time
z	Depth
α_e	Reflection coefficient, long wave
α_s	Reflection coefficient, short wave
γ	Psychrometric constant
ϵ	Emission coefficient
θ	Soil water content
θ_s	Saturated soil water content
λ	Heat conductivity
ϱ	Air density
σ	Stefan – Boltzmann constant
ψ_l	Leaf water pressure
ψ_s	Soil water pressure
ψ_t	Re-scaled soil water pressure

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