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SATELLITE MONITORING OF SEA SURFACE POLLUTION

Gilbert Fielder, Duncan John Telfer, Timothy Stuart Hall,
Lionel Wilson, Richard John Fryer

Lunar and Planetary Unit,
Department of Environmental Sciences,
University of Lancaster,
Lancashire. LA1 4YQ

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16. Abstract Thermal IR data from NASA's Heat Capacity Mapping Mission are used in a study of the feasibility of detecting oil spills in the seas around the UK. The period of observation covered the years 1978/9, in which there were no major spills in the area. A video processor capable of generating false colour renderings of any satellite image from eight density levels was used in the synoptic search for spills. Other laboratory equipment, and associated analyses, were used to study the thermal behaviour of oil spills on water. Oil spills may appear to be warmer or cooler than the surrounding sea, depending on numerous factors. The problem of mapping oil slicks from satellite imagery is investigated, as is the accessibility and usefulness of sea truth.					
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Satellite Monitoring of Sea Surface Pollution

Authors: Gilbert Fielder (P.I.), Duncan John Telfer (Consultant), Timothy Stuart Hall (Co-I.) and Lionel Wilson and Richard John Fryer (Consultant).

Sponsoring Organisations: Goddard Space Flight Centre, Greenbelt, Maryland, U.S.A.; and Department of Industry, London and University of Lancaster, Lancashire, England.

Final Report Number 2-16/F1 for the period 1 January 1977 to 31 October 1980.

PREFACE

2-16/F1-1 Objectives of Investigation

The overall aim of this research is to investigate the feasibility of the use of data drawn from the visible and near-IR (500 to 1 100 nm) and from the thermal-IR (10 500 to 12 500 nm) bands of NASA's Heat Capacity Mapping Mission (Explorer-A) satellite, as applied to the sea surfaces centring on the North Sea, to study marine pollutants, particularly oil. The area is defined in Fig. 1.

2-16/F1-2 Scope of Work

The research divides broadly between the analysis of HCMM satellite imagery of the marine areas around the U.K. and experimental work designed to provide some of the insight needed in the detection of oil spills at sea using the HCMM, or similar, imagery.

The need for analysis of the visible and IR imagery on the synoptic scale led to the development of false colour image processing techniques. The needs of small scale surveys of particular images led us to develop density slicing, and other high resolution image analysis, techniques. The availability, nature, and speed of recovery of existing sea truth was investigated. Methods of filing and of recovery of the incoming satellite pictures were developed.

Outdoor and indoor simulators were used to study the differences in the thermal regimes between systems consisting of uncontaminated water, on the one hand, and water contaminated with oil, on the other. The effects of ambient temperature, humidity and air velocity on the simulator systems were studied.

2-16/F1-3 Conclusions

Video processing techniques appropriate to the semi-quantitative analysis of the HCMM imagery were developed and used in the search for synoptic anomalies in the marine areas

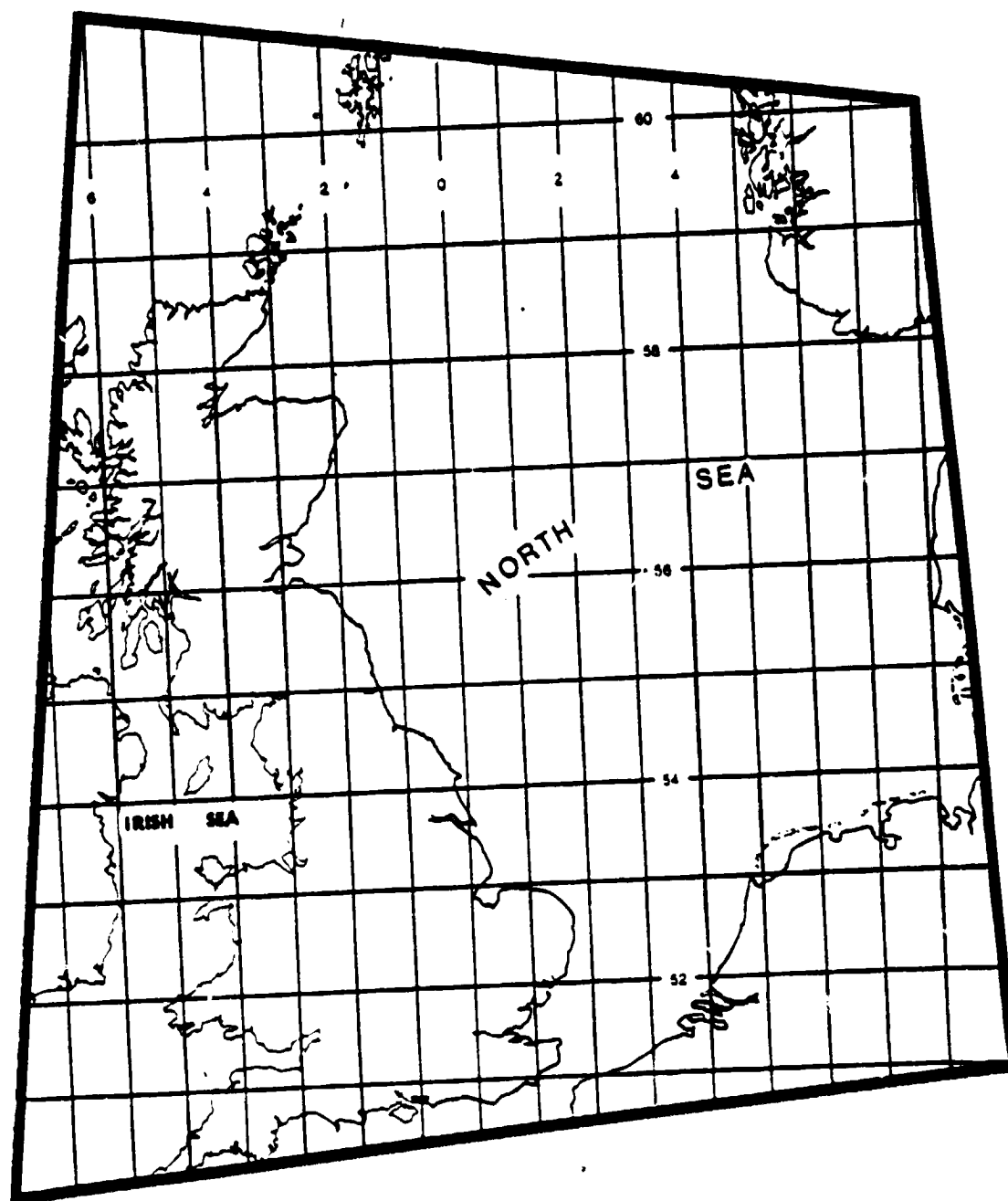


Fig. 1 The quadrangle which limits the area of the present investigation.

around the U.K. In addition, accurate methods of quantitative video line processing - using a PET microcomputer and floppy disc system - were developed and used.

Computer programmes were prepared for mapping the positions of features at sea in relation to coast lines visible in the imagery; and software was written for the operation of the associated I/D position location pad.

Sea truth relating to the areas under investigation is quite inadequate for a sound comparison of the temperature parameter with the thermal IR data from HCMM. However, an HCMM system can produce useful synoptic charts of the relative thermal output from sea areas; and a future system has the potential of generating useful sea surface temperature output.

Controlled experiments on artificial oil slicks in the laboratory environment and in direct sunlight outside have led to a number of important conclusions having direct relevance to the detection and monitoring of oil at sea by satellite. Even if oil is spilled at the same temperature as that of the sea water the oil slick rapidly acquires a different surface temperature; and the thermal regime of an oil-on-water system differs from that of an all-water system. The temperature, and surface property, differences between the two systems lead to ready detection of oil (within the resolution capability of the sensors) in the infra-red waveband. However, the problem is complicated by the fact that the oily surface may appear warmer, or cooler, than the surrounding sea surface; and it follows that under special (rare) circumstances, the two surfaces might be indistinguishable in so far as temperature is concerned. Prediction as to whether a particular oil spill at a specified instant of time will appear warm or cool in relation to the uncontaminated water around the spill can be attempted.

No major spills of oil occurred in the area in question in the period during which HCMM imagery was received of that area, but one small oil spill was probably identified through the thermal IR channel of the HCMM satellite.

A satellite thermal IR system can be useful in the discovery and subsequent monitoring of oil spills at sea provided the image noise level is low, the resolving power is small and the passes are frequent. Such a system is capable of producing useful daytime information in the absence of sea truth. Indeed, although useful pilot studies might be conducted using a sea surface data retrieval system such as ARGOS, we can see the financial practicability of some future oil detection satellite's acting independently from any system involving the collection of sea surface data.

The identification of clouds - the most troublesome sort of noise in the thermal IR - in satellite imagery might be achieved through the use of thermal IR stereometry. Observations in areas of high cloud expectancy might be supplemented through the use of radar techniques. Sources of background noise, such as surface pollutants other than oil, and mist, might be separated from oil effects using their known locational and morphological characteristics. We see computerised flicker techniques and shape factor analyses as of potential for the highlighting and identification of anomaly types.

Although we recommend an upgrading of the present HCM system for use in any future oil detection satellite, the present instrumental system might profitably be used, with a larger pass rate, in the DIR mode for mapping thermal regimes at sea and for producing estimates of sea surface temperatures on a synoptic scale, thus largely supplanting ship measurements of temperature.

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G. Fielder acted principally as project manager, D.J. Telfer principally as operator through Phase 1 (pre-launch) and until 14th April, 1980 in Phase 2, when he resigned as Co-Investigator and became Consultant to facilitate the transition of the co-investigatorship to T.S. Hall, who assumed the appointment from 13th May, 1980, to 30th September, 1980. R.J. Fryer acted as Consultant in the preparation of computerised cartographic routines, L. Wilson as Consultant on the handling and reading of the HCMM CCT's supplied by NASA, as well as on computer matters generally. Miss S. Stackhouse assisted with the cataloguing of HCMM photographs and typed the present report.

TECHNICAL HISTORY OF PROJECT(A) Calendar Year 1977Cartography from Satellite Photographs

Early in 1977, Dr. R.J. Fryer was appointed as Consultant to the Lunar and Planetary Unit to advise on the handling, and the making compatible with the mainframe computer needs, of map and support data to be used in the programme, following receipt of CCT's.

The Consultant developed routines on the mainframe computer (then an ICL 1905 F) for the preparation of maps from geographical data. The following graphical routines were prepared:-

- MERC a subroutine to compute the cartesian co-ordinates, on a Mercator projection, of geographical points supplied as radian latitude/longitude pairs.
- ØTLN a subroutine which draws a rectangular map outline for the final plot and simultaneously initialises some important variables. This subroutine is an essential preliminary to the use of DRSCN, CØAST or GRDTH (see below). Additionally ØTLN enables the user, optionally, to draw a labelled latitude/longitude grid on the map at specified intervals from a specified geographical origin.

DRSCN a subroutine which draws digitised outlines ('scans') on the base-grid prepared by ØTLN by joining successive map positions by straight lines. The subroutine uses EDGPT (see below) to ensure that only those parts of the scan which lie within the map boundaries are drawn.

CØAST this routine is identical to DRSCN with the exception that its data source is from a supplied file rather than from the digitised data derived from the image being analysed. Its purpose is to enable the user to insert, optionally, a stylised coastline on a map when there is no desire to digitise the coastline in an image or where, for various reasons (e.g. cloudover or coastline not in image area), digitised measures of the coastline position are not available.

EDGPT a subroutine to halt drawing of a scan at a map boundary where the scan would otherwise extend out of the map being prepared.

GRDTH a subroutine to enable the annotation of a map with ground-truth data if so required. Geographical positions and alphameric labels are read from computer cards and the labels inserted on the map beside a symbol drawn at the supplied geographical position. Positions outside the map boundary are ignored, and for each position a choice may be made from fourteen available symbols.

These routines are combined, under the control of a master programme, in a single package and stored in a computer file. The file may then be utilised as desired, implementation of the various subroutines being controlled by the values of parameters punched in a single control card.

A sufficient understanding of the orbit and imaging system of the HCMM was gleaned for a start to be made on routines for the transformation of 'image' co-ordinates into 'geographical' co-ordinates.

Technical Developments

By March 1977 D. Telfer completed the design and construction of a low cost 8-level colour video (CCTV) black and white slicer for enhancement and recognition of grey level variations in monochrome prints and transparencies. In trials, the equipment yielded promising results when applied to NOAA-5 imagery obtained from Dundee University. The B/W video camera was a Sony AVC 3250 CE loaned by the Media Services Unit of Lancaster University. A secondhand Bush CTV-25 was employed for display of the false-colour images. Some trials were also conducted using a suite of LANDSAT images of the UK purchased from Nigel Press Associates.

A block diagram of the basic video processor is shown in Fig. 2. The black and white video signal is divided into eight grey levels, each of which may be displayed as a false colour. Three primary colours are added to black until white is produced at the fourth level. Primary colours are then subtracted from white to yield two additional colours at levels five and six. Finally, the colours corresponding to levels seven and eight are obtained by further subtraction operations not confined to white. The main part of the processor uses seven 527 fast comparators with TTL outputs as digital RGB (+ or -).

Grey level range (SPAN) and threshold (SHIFT) are provided, along with variable input (GAIN) and output (SATURATION) levels. The device worked satisfactorily in conjunction with the Bush CTV-25 receiver, which was suitably modified to permit injection of digital RGB signals to the grids of the chrominance output tubes. Delay between chrominance and luminance at the CRT was not significant.

The Sony black and white CCTV camera was equipped with a view finder display which served as a black and white monitor.

During the test runs with NOAA-5 Thermal IR imagery, modifications were made to the processor to improve the quality of the display. The most benefit was achieved from adjustment of the comparator series input resistors. These

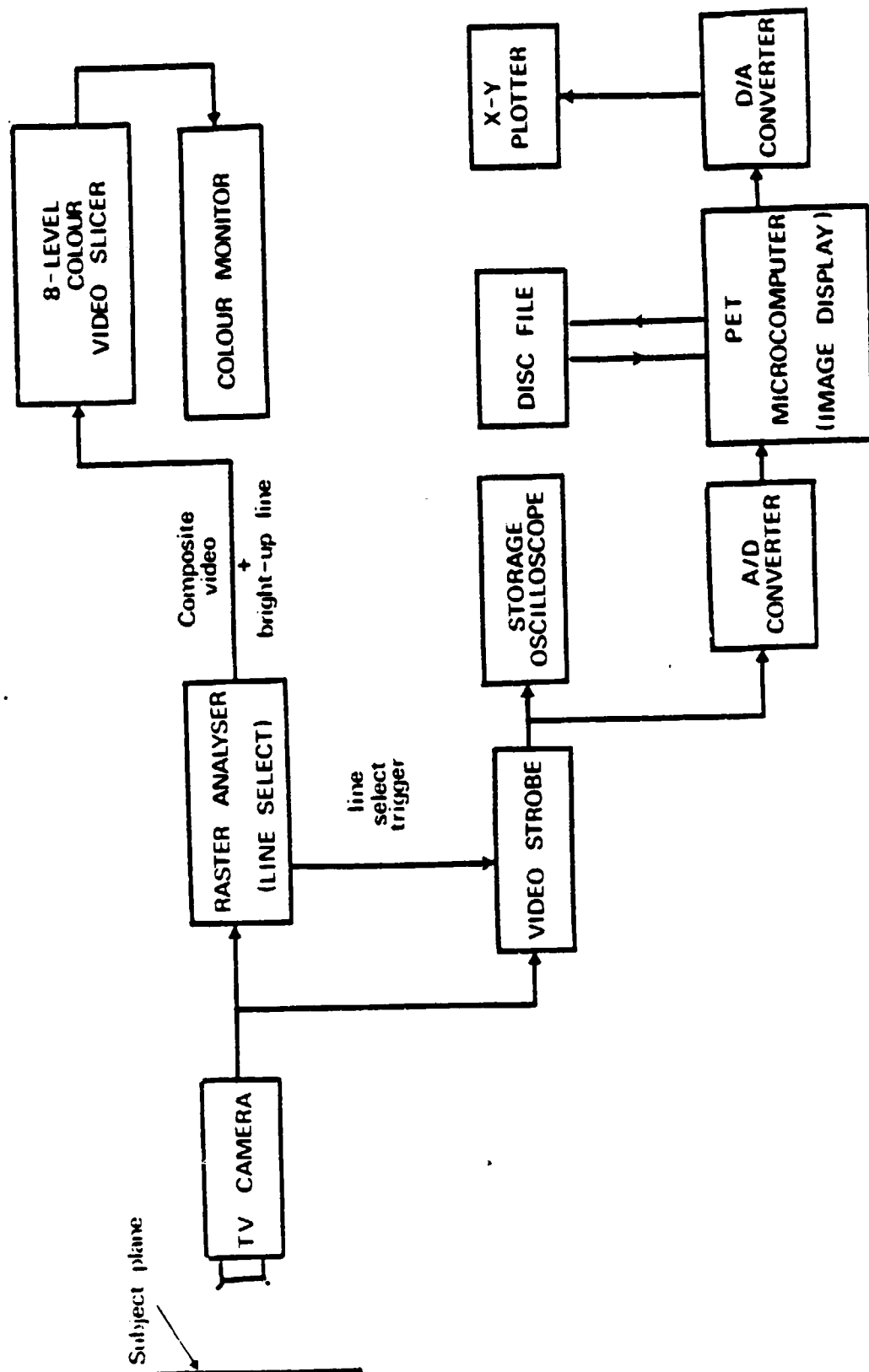


Fig. 2 Block diagram showing microcomputer processing of strobed video signal from TV camera.

were decreased from 4.7 k Ω to 470 Ω . The capability limits of both the CCTV camera and the domestic monitor receiver were reached and further modifications could not be tried until purchase of camera and monitor systems of better quality.

Regarding needs to maximise the video processing capability (synoptic fast processing) with the video processor, we considered, as possibilities, the schemes which are summarised in Figs. 3, 4 and 5.

For synoptic fast processing, we favoured the option shown in Fig. 4. We compared this type of scheme with the IDP 3000 and concluded that our scheme would provide a cost-effective solution to the fast processing of NOAA and HCMM imagery.

We felt justified in claiming that a better camera/tube unit was required because:

- a) The camera shading effects using a vidicon were found to change with image brightness, contrast and structure. This made electronic (analogue of digital) correction of the video wave form difficult. However, improved results could be obtained by having minimal need for a shading correction in the first place. Link Electronics market a camera-tube combination which was effectively demonstrated to us at Imperial College, London. No electronic shading corrector was used on that occasion.
- b) At a visit to Plessey, made on 3rd June by D. Telfer, critical examination of NOAA imagery (Ekofisk oil slick area) included ratio-taking for camera shading corrections, but even with the digital technique spurious colour rings were evident in the display. It was felt that the IDP 3000 could benefit from improvements at the camera end of the system.

In addition, the visits made to Plessey demonstrated that a good quality monitor is an essential part of a video processing system. Plessey strongly recommended to us the Crow Electronics model used in the IDP 3000; this had been chosen by them following assessment of alternative monitors. Although at

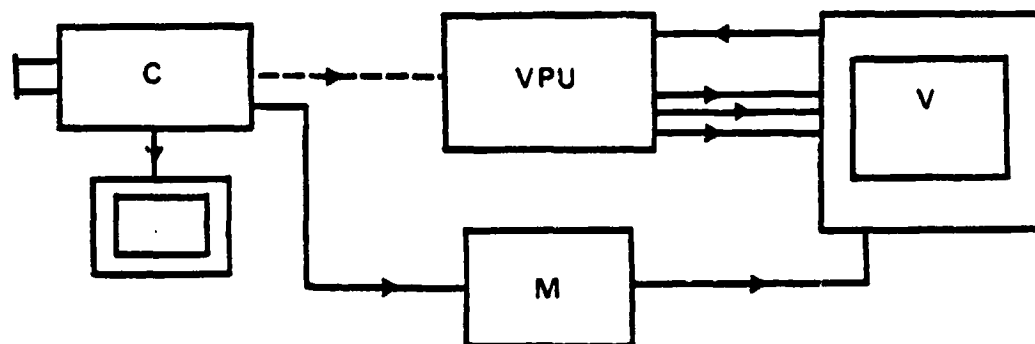


Fig. 3 Video processing configuration used up to March 1977
C = Black-and-white Sony CCTV camera; M = Video modulator
built by D. Telfer; V = CTV 25 Bush T/V receiver; VPU =
video processor built by D. Telfer.

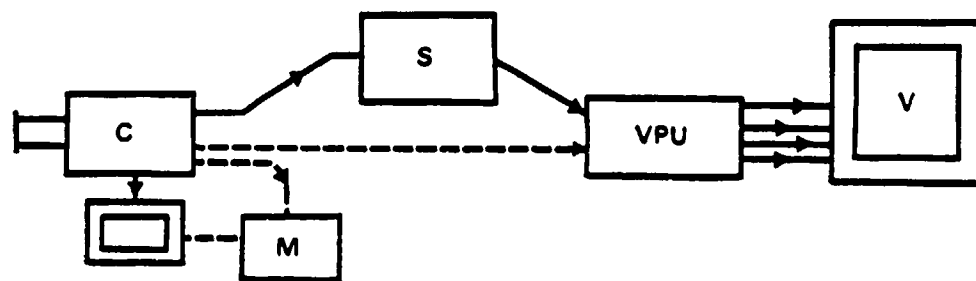


Fig. 4 Analogue shading correction with improved camera and monitor C = CCTV camera with low shade vidicon, Link Electronics Limited (£550); S = Analogue shading corrector, Cox Electronics (£650); V = Colour video display monitor, Crow Electronics, as recommended by Plessey (£3 000)

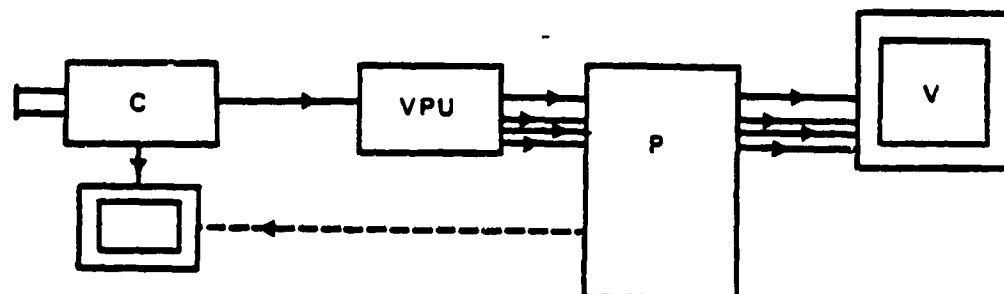


Fig. 5 Digital correction with improved camera and monitor
 C = CCTV b/w camera, as in Fig. 4; V = Colour monitor, as
 in Fig. 4; P = Plessey image processing console with minimum
 requirements for storage and digital correction for shading.
 This includes only the necessary stores, viz., 3 bit output, 8
 waveband for 640 x 480 picture elements; store and waveband
 controllers, and ratio unit with modification for real-time
 control override. Estimated cost (Plessey) £50 000.

N.B. Shading effects were apparent in the displayed imagery on
 the IDP 3000 during a visit to Plessey (see below). It
 was noted that a relatively inexpensive CCTV camera was
 being used.

£3 000 this would be the most costly item in our preferred option (Fig. 4), the indications were that this colour monitor could improve image definition by at least an order of magnitude.

D. Telfer also designed circuitry for a colour-selective area integrator to be used in conjunction with our video processor. Following discussions with the Department of Industry, a provisional patent was applied for in connection with the video processor. Microwave Modules Ltd., Liverpool, were approached regarding the possibility of marketing the device should sufficient interest be shown. A further set of experiments was undertaken to evaluate the usefulness of optical diffraction filtering in conjunction with the video processor and results were promising for the test image used, which was an Orbiter picture of the lunar surface containing raster lines. These were successfully removed.

As an alternative to the rather more expensive Crow Electronics (Barco) colour monitor, the Sony Trinitron was evaluated.

Delivery was taken on the D.O.T. Products, Incorporated, "Compo 2" additive viewer with a projection facility. This was tested in the synoptic fast processing of HCMM and support imagery. The viewer was first established by Mr. N. Press of Nigel Press Associates in October 1977.

Visit to the USA by D. Telfer, 7th-16th November 1977

This visit was arranged primarily in response to a communication from the D.O.I. concerning recent developments in remote sensing of oil pollution by the United States Coast Guard (U.S.C.G.) although the opportunity was taken to visit other relevant establishments in the eastern United States. Contributions to the U.S.C.G. research programme on oil detection were being managed by Lt. Cdr. J.C.R. White, and D. Telfer visited him at the Washington headquarters of the U.S.C.G. on 7th November 1977.

The current activities of the U.S.C.G. were found to be yielding useful results derived from day/night aircraft over-

flights of oil spills using side-looking radar, an IR/UV line scanner, an aerial reconnaissance camera and a passive microwave imager. Operations with this system have already logged several oil spills, and the results were discussed in detail. Clear images of oil slicks were produced by the IR line scanner: the results were comparable to those gained by the French organisation G.C.T.A. (Groupement pour le développement de la télédétection aérospatiale) over the Ekofisk blow-out in the North Sea, and show that thermal IR detection of oil is a most promising technique.

A second important visit was made to NASA (MD) to contact as many as practicable of the staff who were involved in HCMM and to exchange information about progress in the present project and matters arising therefrom. The principal personnel contacts were with the HCMM Investigations Manager, Mr. Locke Stuart, who, following a discussion of our data requests, pointed out that thermal inertia maps will not now be supplied unless specifically requested for areas of extreme interest within the scene under investigation; the Technical Officer, Mr. H. Oseroff, with whom the data mailing arrangements were discussed and clarified; Dr. J. Vette, Director of the World Data Center A for Rockets and Satellites; and HCMM Project Scientist Dr. J. Price. Possible points of relevance concerning NASA's proposed contribution to the Climate Program were investigated in discussions with Mr. L. Hogarth and Dr. W. Bandeen. Use of satellite imagery other than that from HCMM was considered both as possible accessory material to the HCMM data and in the context of contingency plans should there be a launch failure, or other difficulties, in connection with the Explorer A satellite.

At NOAA (World Weather Building, Washington) the technical aspects and acquisition of NOAA imagery were discussed with Dr. W. Jaeger and Mr. L. Berry, respectively.

The Marine Station at Woods Hole was visited on Friday 11th November, when D. Telfer met Dr. B. Butman to discuss and exchange information about sea-data measurements. As a result of this visit, we expect to receive a copy of the report apper-

taining to the portable sensing platform which has been developed at Woods Hole for measuring sea-surface parameters including temperature, salinity, turbidity and current.

On 14th November, D. Telfer visited M.I.T., Boston, and discussed applications of "whole-Earth" synoptic imagery, and infra-red and radar techniques, with P. Rosencrantz. Back-up meteorological imagery of 1 km resolution from NOAA was considered to be of some value in the HCMM work.

At the University of Massachusetts, Amherst, D. Telfer was able to discuss the remote sensing of planetary surfaces in the visible, UV and near-IR, with Professor R. Huguenin. Another discussion with Dr. K. Beechis centred on the usefulness of passive microwave radiometry in thermal and textural investigations of water surfaces, and on the possible application of this technique to complement IR measurements in our simulator experiments at Lancaster.

D. Telfer rounded off his visit to the USA on Wednesday 16th November by having discussions, at the Graduate School of Oceanography (University of Rhode Island), with W. Mosher on aerosols and trace element enrichment in the atmosphere and on the subject of the generation of these particles from natural sources; and by noting the results of Dr. T. Huang's studies of marine sediments.

Visits in the UK

On 3rd October 1977 D. Telfer visited Dr. Alison Cook and Mr. T. Welch to view the remote sensing equipment in the Department of Geography of the University of Sheffield.

G. Fielder and D. Telfer travelled to Aberdeen on 10th October 1977 and, on 11th October, entered profitable discussions on North Sea truth with Dr. H. Dooley of the Marine Laboratory of the Department of Agriculture and Fisheries for Scotland. The team leader in pollution, Dr. MacIntyre, and a specialist in the chemical aspects of oil pollution, Dr. W. Johnston, were also involved in the discussions, which covered other points of contact, specific problems (such as fog) likely to arise in HCMM remote sensing of the North Sea surface

(based partly on NOAA data), the nature and temperature of effluents currently discharged into home waters, and other factors (such as chlorophyll, dredging effects and jellyfish shoals) which might complicate the interpretation of remote sensing data relating to the North and Irish Seas.

Sea Truth

A survey of existing sources of sea-level data was initiated. Informal plans were laid for the acquisition of temperature, salinity and plankton bloom data from a part of the Irish Sea (which will be used to provide control data), and for the acquisition of temperature and sea current data from parts of the North Sea.

In preparation for the ready identification of marine features on satellite pictures, maps having a 1:500 000 scale were purchased in the second quarter of 1977 to provide a definition of the coast lines of Britain and the west European continent. This scale was selected to provide map positions to an apparent accuracy only slightly less than the expected resolution to be provided by the HCM. In those instances in which Ordnance maps were out-of-print and unobtainable, Aeronautical maps were procured in their place. Both series of maps were prepared on the Lambert Conformal Conic projection. One wall of a cartographic room was covered with Sundeala board to receive the map mosaic.

The geographical co-ordinates of oil rigs in the North Sea were received, with rig identifications, from M. Sturgeon of the Department of Energy.

G. Fielder continued the survey of sources of sea truth relevant to the present programme and received informative letters from Dr. L.E.J. Roberts, A.E.R.C. (Harwell); R.K. Webster, A.E.R.E.; Dr. V. Essex, S.R.C.; Dr. B. Jamieson, N.E.R.C.; E.A. Stephens, I.G.S. (London); D.A. Ardu, I.G.S. (Edinburgh); Dr. T.C. O'Connor, University College Galway; and J. Smythe, Occidental. All these responses were positive only in that they referred to potentially useful points of contact. However, it was clear that some sea truth could be provided

through Dr. P. Driver, Lancashire and Western Sea Fisheries and through Dr. E. Monahan, University College, Galway. Dr. Monahan's Irish Sea programme collects temperature, salinity, chlorophyl, nutrient and other data.

A mosaic of the 1:500 000 Aeronautical maps of the North Sea area was prepared during the third quarter and mounted on Sundeala board in an Operations Room, this series of maps being found more suitable than the Ordnance maps of the same scale and projection for defining the area under investigation. A second set of relatively undistorted Aeronautical maps was bought for the purpose of the definition of coastline data to an accuracy adequate to feed to the computer's subroutine ØTLN.

G. Fielder continued to survey sources of sea truth and received replies from the following organisations:-

Continental Shelf Institute, Trondheim (J.O. Klepsvik).

Department of Agriculture and Fisheries for Scotland,

Marine Laboratory, Aberdeen (B.B. Parish).

Department of the Environment, London (J.M. Williams).

Harwell, Nuclear Physics Division H8 (J.A. Cookson).

Institute of Hydrology, Wallingford (J.S.G. McCulloch and K. Blyth).

Institute of Oceanographic Sciences, Birkenhead (D.E. Cartwright).

Institute of Oceanographic Sciences, Wormley (Mrs. P.M.D. Hargreaves).

Meteorological Office, Bracknell (J.L. Brownscombe).

Ministry of Defence, Hydrographic Department, London (Lt/Cdr. T. McAndrew).

Ministry of Public Health and Family, Brussels (M.J.P. Monnaerts).

Of these organisations, the Scientific Attache of the Brussels Ministry offered to provide us with all the sea truth data which may be of interest to us, in exchange for remote sensing data and our own, or our joint (collaborative), interpretation of those data. Again, D.A.A.F.S. (Aberdeen) wished to explore the possibility of their supplying relevant sea truth data to us.

Enquiries about certain lines of application of the present research programme were received from the Central Office of Information, London, the Liberal Whip's Office, London, Norpipe Petroleum U.K. Ltd., Middlesbrough, and Tioxide International Ltd., Stockton-on-Tees.

Methods of measuring sea surface temperature were researched by D. Telfer. In a visit to E.G. and G. Geophysical Ltd., Bracknell, in late June, D. Telfer learned that they could be in a position to obtain sea surface data to special order but at a cost of the order of £3 000 per day.

Further research on the sources and acquisition of sea surface data was completed in December 1977 by G. Fielder and the following organisations should be in a position to provide relevant data during Phase 2 of the programme:-

Fleet Weather and Oceanographic Centre
Meteorological Office
Department of Agriculture and Fisheries for Scotland
Ministry of Agriculture, Fisheries and Food
Deutsches Hydrographisches Institut
Institut Francais de Petrole
Lancashire and Western Sea Fisheries
Dept. Physical Oceanography, Univ. Coll. N. Wales
Hydrographic Department, Ministry of Defence
Marine Information and Advisory Service, I.O.S.
British Aircraft Corporation
Brussels Ministry of Public Health and the Family
Water Research Centre
Tioxide International Ltd.
University College Galway
E. G. and G. Geophysical Ltd.

The data derive chiefly from a variety of vessels but also from sea platforms and bouys. One major problem over the rapid interpretation of synoptic satellite data in association with sea truth lies in the delay commonly experienced between the acquisition of the sea data and their release to the scientific community.

Satellite Data

NOAA pictures of the region including the Ekofisk slick were obtained through Dundee and examined using both the video processor and the Plessey IDP 3000 Digital Image Processor. Cloud cover prevented effective interpretation of the data.

Simulation Equipment

In order to test and develop pollution detection and monitoring techniques under controlled conditions, plans were laid for an outdoor simulator consisting essentially of two 100 gallon capacity water tanks, with filling and emptying facilities, viewed by a battery of optical and infra-red sensors riding on an overhead gantry. A site for this equipment was selected, and delivery taken of the polyurethane tanks. A mount for two reflex cameras was designed and built. In addition, two Eltec infra-red sensors were ordered.

By September 1977, the gantry of the outdoor simulator had been assembled and erected on a specially constructed reinforced concrete pad in the grounds of the University of Lancaster. The gantry, which rotates in a vertical plane which is itself inclined at 45° W of geographical north, was designed to carry two optical cameras and one of two Eltec IR sensors. The orientation of the plane of rotation of the gantry was set by map measurements and checked using a magnetic compass and taking a variation of 8° W. The orientation error was estimated to be not more than $\pm 1^{\circ}$ of azimuth. Thus the plane in which the simulator sensors rotate is identified with the orbital plane of the HCMM satellite in a daytime pass.

A 20 mm O/D outdoor water tap was fitted close to the simulator pad and plastic hoses for filling and emptying the polyurethane tanks were bought. Oil contaminating the water which is being put to waste is removed by special filters in the drainage system.

(B) Calendar Year 1978

Mapping from HCMM Images

R.J. Fryer reported usefully on the problems likely to be encountered in the work of relating points in HCMM imagery to fixed co-ordinates on the Earth's surface.

PAL-encoder and matrix

Equipment for performing first-look operations on the basis of the use of colour video presentation of grey-level, sliced black and white images using a CCTV camera was developed further.

To enable acceptance of colour video information through the composite video input or into the UHF aerial of a TV monitor, a PAL system encoder interface was designed and assembled for use with the grey-level slicer. The latter provides digital red, green and blue colour information which must be converted via a suitable matrix circuit to colour-difference signals, namely, red-minus luminance (R-Y) and blue-minus luminance (B-Y). These are injected into the encoder along with timing pulses for the chroma-burst signals appropriate for acceptance of the total video information, by the decoding circuits of a PAL receiver/monitor. In the PAL system it is necessary to switch the phase of the (R-Y) signal every alternate line; provision for this is included in the matrix before the encoder.

A block schematic of the PAL interface is shown in Fig. 6.

Colour Monitor

It was decided to purchase a SONY model, CUM-1801 UB, which gave pictures of acceptable definition during trials with LANDSAT and NOAA imagery, and which compared favourably in performance with more expensive monitors.

CCTV Black and White Camera

A different B/W camera was tried: this was a S/H ITC model with a silicon diode tube. This model was then replaced by a

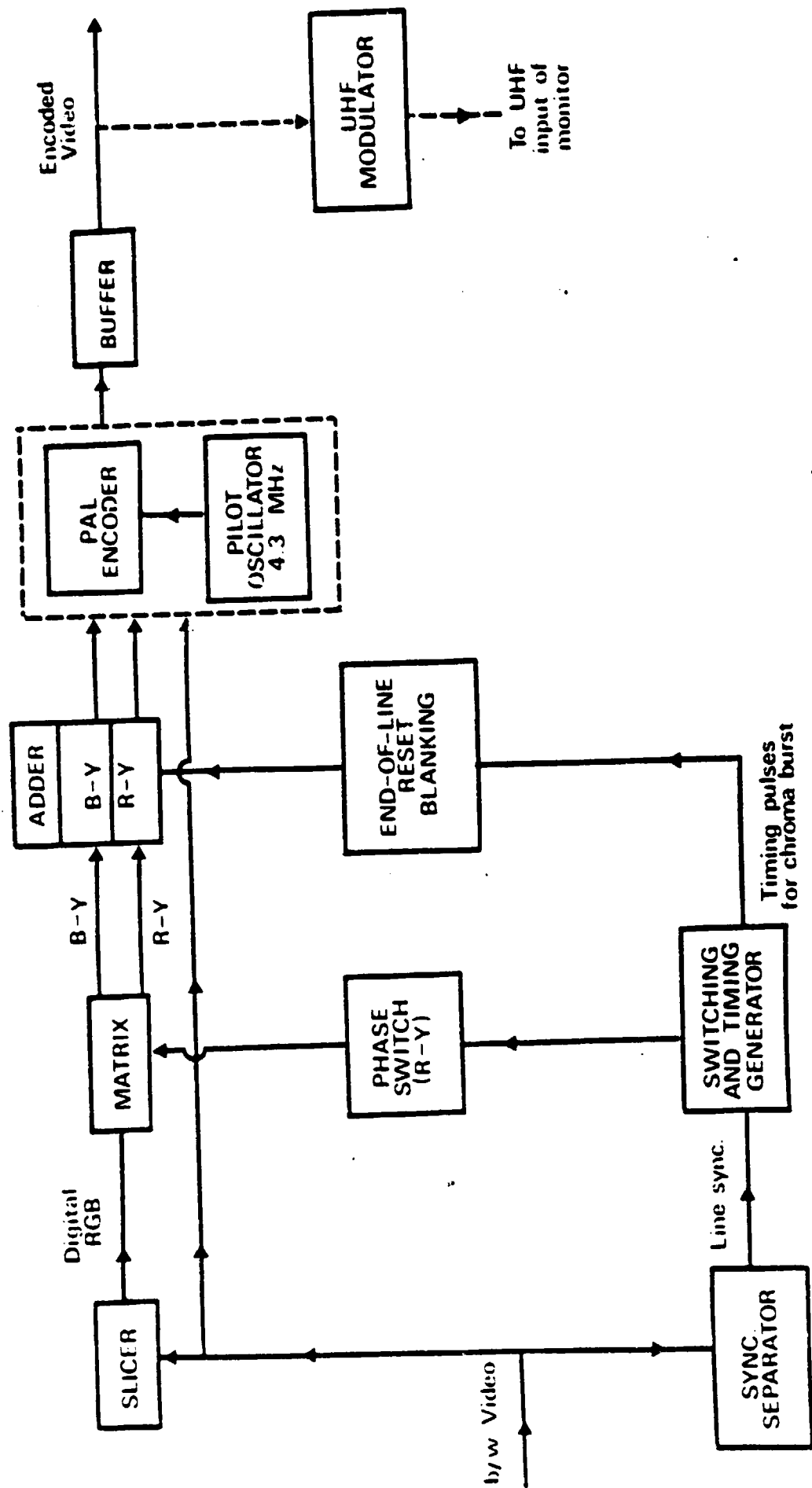


Fig. 6 Schematic block diagram of PAL interface

Link Electronics Model 109, a camera specially selected for its high grade vidicon tube of low shading characteristics, which, later, was also fitted with a silicon diode tube.

Videodensitrometry

Single line selection, using a purpose-built raster analyser from Video Electronics Ltd., Manchester, enabled us to display density profiles of black and white imagery on a storage oscilloscope. Positive LANDSAT and NOAA prints were examined, in this way, and grey-scales were used for calibration runs. Using video signals from the camera output, the amplitude resolution attained by the method exceeded our expectations.

Optical Filtering

A small He/Ne laser and its accessories were ordered, following the successful trials using equipment borrowed from the Department of Physics, University of Lancaster.

Compo-2 Additive Viewer

The high quality optics, the projection facility, and the ease of operation (using the convenient control panel) of this instrument make it particularly suitable for our purposes. As D. Telfer discovered during his visit to NASA, the necessity for hand-registration of day/night HCMM imagery has precluded the possibility of NASA's supplying thermal inertia maps as a routine procedure. However, following tests with the Compo-2, we considered that we could effectively assess the usefulness of day/night data, and extract other information directly, using the instrument's projection facility in conjunction with our video processing equipment.

Quantitative Processing

Results with a storage oscilloscope type of display of selected lines of satellite imagery encouraged us to consider the profitability of storing and processing parts of the video output obtained from the CCTV camera. In addition to plans to make use of existing University facilities, we considered the

incorporation of a dedicated microcomputer system into our video processing facility. A number of hardware, and associated software, options were reviewed. These included mini- and micro-computer systems.

On 27th January 1978, D.J. Telfer visited Dr. C. Taylor at the Medical Biophysics Unit, University of Manchester, to see a Joyce-Loebl Magiscan digital image analyser demonstrated. This programmable system is based on a Nova minicomputer with the additional hardware and software developed at Manchester University. It is intended, we understand, to make the equipment available for solving external users' problems; an opportunity in which we have expressed interest should the need arise. A Quantimet image analyser was also seen on display at a Royal Society Exhibition in London.

Analysis

Following further trials using the additive viewer, grey-level slicer and video densitometer, purchase of a Telequipment DM63 storage oscilloscope enabled us to implement tests of quantitative intensity determinations on LANDSAT imagery, using grey-scale calibration. The results confirmed that this technique would be of invaluable assistance in our assessment of HCMH imagery. We also experimented with Explorer-A scans of the eastern seaboard of the USA received from NASA.

A Commodore PET2000 microcomputer was purchased with a view to video line processing in the quantitative analysis of images. The method was planned by Dr. Telfer according to the following scheme: a stored portion of the image to be analysed (part of a raster line) is combined in a chosen way (e.g., subtraction, division) with the video image data to give an image profile plot corrected for the TV camera shading at an XY plotter. The peripheral hardware was initially committed to our electronics workshop, but D. Telfer designed and built the video strobe interface for use with the CCTV camera.

Programs were evolved for image correction and these were stored initially on cassette tape. Up to this time a reliable floppy disk drive was not available in the UK for use with the Commodore PET microcomputer (but see page 29).

Improvements to the sharpness and degree of edge enhancement of the CCTV imagery were effected electronically. Further improvements were gained by mounting transparencies on the stage of a low-power microscope, illuminating them by means of a projector lamp arranged to back-light the condenser lens. The image was viewed with our TV camera receiving light through the eyepiece of the microscope. This arrangement is useful for the examination of picture data at high resolution. Furthermore, the system has been found to produce a noticeably flatter effective illumination field than in the case of front-illuminated prints viewed directly by the TV camera.

Trials with the test imagery of the U.K. coastal regions again demonstrated the usefulness of the videodensitometric technique. Steps were then taken to interface the signals with the PET microprocessor system so that the quantitative measurements, incorporating a camera shading correction, could be implemented. A Creed teleprinter for providing hard copy of picture data held in the microcomputer was obtained.

Data Handling

In order to facilitate the conversion of data from the digital to the analogue form, and vice versa, for the generation of hard copy of data on an XY plotter, and for the CCTV display of data, we commissioned the Psychology Department of Lancaster University to construct D to A and A to D converters for use with the microcomputer.

Software for Data Processing

D. Telfer continued to develop further microcomputer routines for use in processing a given HCMM image, in which picture elements are sampled at video frame frequency. TV camera shading corrections were evolved. Refinements to the routines for image rectification were also prepared by D. Telfer, using polar co-ordinates.

Visits

On 20th June 1978 Dr. R.J. Gurney and Dr. S.F. Jagger of the Institute of Hydrology, Wallingford, and Mr. K. Blyth of

the University of Leeds, visited the LPU to discuss points of mutual interest on the HCMM project. The principle discussions centred on correction procedures and cartographic problems.

On 21st September 1978, D. Telfer visited Dr. J. Hardy in the Department of Geography of Reading University to discuss the status of our respective projects. D. Telfer was able to view a demonstration of the Image Science colour video slicer applied to the recent Explorer A imagery and he found that the results were comparable to ours.

In a visit to the Transport and Road Research Laboratory at Crowthorne, on 21st September, D. Telfer discussed sources of good quality supplementary imagery and current developments in image processing and analysis with Warren Heath.

At the Microcomputer Exhibition (sponsored by 'Personal Computer World') held in London on 22nd September, D. Telfer was able to make an appreciation of the present technical and market status of microprocessors and microcomputers. Associated peripheral instrumentation was also examined. Some printers were examined but most were considered unsuitable for our purposes. .

D. Telfer visited NORSG/Swindon (N.E.R.C. Oceanographic Remote Sensing Group) on 9th November 1978 for an interesting and useful meeting at which contacts were made with 17 other people in the U.K. directly concerned with remote sensing of the marine environment.

Sea surface temperature data were obtained for the Liverpool Bay area at the beginning of June 1978, corresponding to IR imagery from NASA for that period.

The Chairman, Dr. J. Simpson, of the UCNW Marine Research Unit, Anglesey, showed particular interest in our requirements and image processing facilities at Lancaster, which he also saw during a recent visit.

Tiros N imagery from Dundee University was shown to us by P. Bayliss and considered to be of potential use in the HCMM work.

Receipt of First Test Data from HCMM

The Explorer-AEM-A satellite was launched on 26th April, 1978, and, thereafter, the regular orbital adjustments were completed. We received the first test data in the form of three pictures of the eastern coastline of N. America in June.

Further Test Imagery Received

By September 1978, we had received two test-data images (one in the visible band and one night-time IR photograph), showing parts of the U.K. coastline. NASA reported that these images were substandard in several respects. Tests on the IR image with the grey-level slicer showed clear differences, on the synoptic scale, between exposed estuarine deposits and a part of the North Sea. Contrasts away from coasts were less conspicuous but, although complicated by the superimposed raster, could be detected using the video line-scan densitometer. We awaited arrival of the first standard data relating to the North and Irish Seas.

Further test picture data arrived on 3rd November, 1978. Up to that time we had received a total of 12 images of 8 areas in the North Sea and 1 area in the Irish Sea/North Atlantic Ocean.

For "vertical" images composed from 620 km altitude the predicted resolution in either of the channels was about $600 \times 600 \text{ m}^2$. Measurements made by G. Fielder on a night IR image of the west coast of the U.K. showed that this resolution was essentially attained. Many thermal fronts in the marine areas were sharply delineated on the images provided by NASA. D-MAC card-print-outs of positions were obtained, on prints received, for survey purposes in the first instance.

For test purposes, using the unenlarged hard copy HCMM positive prints in conjunction with the D-MAC plotter, it was possible to develop a microprocessor data filing and handling system for processing cassette data tapes for each HCMM image for rectifying co-ordinates in terms of any given map projection, using known coastline features for calibration. Test carried out on HCMM IR imagery for 1st June 1978 showed that image

features can be plotted in terms of map-co-ordinates by this technique to within a few minutes of arc. Refinements to the program were in progress and were expected to improve the plotting accuracy.

Indoor Simulation Equipment

The two gallons of crude oil for use in experiments with the simulation equipment were received gratis from Norpipe Petroleum Limited (U.K.).

Laboratory tests were carried out with an IR sensor to compare the emissivity of water and oil-on-water. In the case of a film of North Sea oil covering an equal volume of water, and in which the equipment had been left to attain thermal equilibrium, the measured responses of the systems were mutually different, with a general tendency of the oil surface to be warmer by an estimated 1 or 2 K.

Outdoor Simulation Equipment

Two 35 mm cameras and an Eltec IR sensor were mounted in such a way that they could be carried, singly or together, by the rotating gantry of the simulator. In addition, a chopper assembly was mounted in front of the IR sensitive surface in order to introduce the capability of distinguishing the response from the water, or oil-on-water, from the overall response including background noise. The detector/chopper system was tested with the aid of a recently acquired Ortec-Brookdeal phase sensitive detector. In the high positions of the gantry, the IR sensor and cameras are out of reach. Furthermore, the solar radiation incident on the tank fluids would be interrupted by an operator near to the battery of sensors. Hence the latter was to be actuated by remote control. To this end, cables were run to the Eltec sensor and chopper, and air tubes were connected to the shutter mechanisms of the respective cameras. The whole sensor assembly was moved along the gantry by means of a cord and pulley system: in this way the sensors could be directed at each tank in rapid succession before the conditions of solar

illumination changed. A water-powered extractor pump was incorporated in the plastic water hose system for the rapid exchange of tank fluids.

Sea Truth

The locations of foreign oil and gas platforms in the North Sea were noted using the Offshore Promotional Services Ltd., North Sea Concession Map. A principal source of sea truth, through Phase 2, will be the Meteorological Office (METO). Data from vessels, platforms and buoys will be made available to us through METO 12c. The potential of deriving subsidiary data from ASSFS, MAFF, LAWSF, and the previously mentioned organisations was established.

(C) Calendar Year 1979

Extension of Hardware

Purchase of Computhink Floppy disk system and memory expansion for the PET microcomputer (27 K) greatly increased the speed and flexibility of the small systems data handling facility.

Data

By March 1979, we had received images covering a total of sixteen scenes of marine areas in the vicinity of the British Isles. Apparently, no data were degraded by loss of performance of the power system of HCMM; but routine data acquisition from the satellite was terminated on 1st March, 1979 (telex, NASA to G. Fielder, 16th March, 1979). Apart from the backlog of HCMM data expected to arrive at our laboratories we understood that alternative data may also be made available to us should the need arise.

Further Software Development

Advantage was taken of the continuing delay in the receipt of standard data to develop further the methods of handling both analogue and digital data-formats. Fuller use was made of the synoptic fast-processing facility by expanding the processing

options of the digitised TV camera waveform. This introduced the option of further processing of the imagery in blocks. First, an area of interest of a colour density-sliced image seen on the colour video monitor was selected by inspection. In this way, the choice of block was settled and the relevant brightness data presented in digitised form. In order to achieve this result, various items of software were developed:

- a) Data strobing program. With the aid of the interface constructed by D. Telfer the camera wave-form is digitised and strobed in to the PET microcomputer. The PET then creates a data file in blocks of 225 x 25 data points, each of which is an 8-bit byte giving a maximum of 256 density levels. In practice, the upper limit is fixed at 250 levels.
- b) File handling programs. These programs are used to select blocks of data from a master file created in program (a). Thus, a 40 x 25 array of data points can be presented on the video display unit of the PET. The blocks of data points can then be re-filed on floppy disk.
- c) File reading program. These programs enable one to read the contents of any named file for a block of imagery and to present the results of processing that file on the PET screen. The processing can take the form of (i) camera correction (shading, and electronic, errors) and (ii) illumination correction.

NOTE: In programs (a) and (c) there is the option for the output of the digitised and corrected video wave-forms on an XY plotter.

A number of successful trials were completed. In particular, in the case of an area measuring some 100 x 20 km² to the west of Stavanger (Norway) a daytime, IR positive print recorded on 28th May, 1978 was contrast-stretched to clarify the apparent 1:1 correspondence between the gross features on the print, on the one hand, and the data block, on the other.

Visits

In the first quarter of the year, D. Telfer undertook visits to the following establishments:-

Department of Geography, Sheffield University, 2nd February: the acquisition and processing of radar imagery (SLR) was discussed with Dr. Alison Cooke.

NERC Oceanographic Remote Sensing Group, Alhambra House, 9th February: at the MORSG meeting, an update on the status of projects involving experimentation, and the processing of imagery and other data, in relation to the marine and oceanographic research activities in the UK was assimilated.

Farnborough (NPOC), 22nd February: this was a meeting at the UK National Point of Contact with Earthnet (the European Remote Sensing Group) arranged in conjunction with the Remote Sensing Society. An overview was taken of the reported data and image processing facilities. Contact was made with Keith Ragot and his colleagues with a view to acquiring high quality data/image products as and when required; and the opportunity was taken to assess the usefulness of the IDP 3000 in its present form.

The Warren Spring Laboratory, 23rd February: in a meeting with Dr. D. Cormack and his colleagues the Eleni-V and the Amoco Cadiz events were reviewed, and the results of the appropriate aircraft overflights (in which IR-sensors were employed) were examined. As in the case of earlier US Coastguard experiments of a similar nature, it was noted that the thicker parts of a slick of oil showed warmer, and the thinner parts cooler, than the surrounding water surface.

The possibility of collaboration over the question of synchronism of data acquisition (viz MCMM and further marine overflight experiments) was also discussed.

University College, London, 23rd February: a meeting was held with T. Fountain, to discuss "cellular logic" image processing. The concept of intelligent data points was explored and there was a demonstration of pattern recognition equipment.

NERC (Tidal Institute, Bidston Observatory), 10th August:
Dr. Cartwright's group was visited to discuss sea truth in the
context of the forthcoming MARSEN experiment in the German Bight.

First Official Data from the HCMM Satellite

The official date of first receipt of data was 30th April, 1979. Transparencies covering a total of 32 areas close to the UK were received since that date and were coded, catalogued and filed for ready access. Also since 30th April, 1979, 33 photographic scenes copied from "quick look" HCMM imagery arrived from the Lannion Centre for Space Meteorology, France.

(D) Period 1st January 1980 to 30th September 1980

Personnel Changes

D. Telfer, Co-investigator, left the University of Lancaster on 14th April, 1980 and was replaced by T. Hall on 13th May. Between his leaving Lancaster and 10th September, 1980, Dr. Telfer continued to liaise with the P.I. in a consultancy capacity. Mr. Hall soon assumed full operator duties in the handling and analysis of the HCMM imagery, and in the use of the outdoor simulator and the laboratory wind tunnel.

Satellite Data

A total of 2117 positive and negative HCMM transparencies covering parts of the marine areas around the UK were received from NASA in the period 30th April 1979 to 4th September 1980. These transparencies probably represent all the available standing order data: they were coded, catalogued both manually and on magnetic tape, and filed. Since 8th June, 1979, 1077 Lannion QL positive and/or negative HCMM prints were also received. These prints were, likewise, coded, catalogued and filed.

Sea Truth

A good quality transparency was selected as the best cloud-free HCMM image of the Morecambe Bay area, which is an area

intensively studied by the Lancashire and Western Sea Fisheries (LWSF). Sea surface temperatures and isotherms relating to a small part of the area were acquired from the LWSF (Drs. P.A. Driver and C.M.C. Vivian) and the same area was examined in false colour and scanned using the videodensitometer. Unfortunately, the LWSF sea surface data related to too small an area (close to the shore line) to be of use in the calibration of the HCMM image. Other test cases of similar origin would not have improved on this negative result.

A plan to use sea truth relating to controlled releases of oil on the sea by the Warren Spring Laboratory of the Department of Industry, in order to calibrate HCMM images, was discarded when it was established that a volume of oil some two orders of magnitude greater than that permitted in the Warren Spring programme would be required were such a slick to be detected using the HCMM satellite.

No further updates of reported oil slicks around the UK were received and no major spills were reported in the period under review.

Search Through Data Bank of Imagery

Using our card-index of oil spills reported in the calendar years 1978 and 1979 and in the sea areas under investigation, imagery covering each location, in turn, was extracted from the data bank using the PET microcomputer and the appropriate software development. Images which were "clouded" over the area in question were rejected. The remaining images were subject to full processing but not a single relevant anomaly was found in the first instance.

For the purpose of checking that the imagery was capable of resolving thermal sources of small extent, a number of high capacity electricity generating stations in England, Wales and Scotland were examined. Extraction of suitable imagery from the data bank followed the method used in the search for oil slicks. The results of this search were satisfactory in that, whereas some of the stations were not detectable, others were seen readily.

Further Results Using Wind Tunnel

Some technical development was necessary in order to modify the wind tunnel system in such a way as to simulate winter conditions, at sea, in which the air temperature was below that of the fluids in the trays. After testing different methods of achieving such a temperature imbalance, we consolidated on the use of thermostatically controlled electric heaters fully immersed in each of the liquid systems in the trays. Study of the results showed that the system with the oil spill gained more heat from the flowing air than did the all-water system, even though the wind was now cooler than the liquids. Thus, the results for summer, and for winter, conditions (for water which was, essentially, static) are qualitatively the same: the system with the oil layer becomes warmer as the wind speed increases over the range 1 to 9 ms^{-1} .

(A) Video Processing System

Because of the large volume of picture data to be handled, it was decided at the outset to make use of equipment which would increase the speed of synoptic viewing of imagery and, at the same time, increase the reliability over the unaided visual method in the detection of anomalies in that imagery. It was further decided that the equipment should be capable of application to the detailed surveying of any such anomalies.

Accordingly, and after surveying the market for suitable commercial equipment, Dr. D. Telfer designed and constructed an eight level colour video black and white density slicer, with attendant storage oscilloscope videodensitometer for the generation of line density profiles. Output waveforms could be digitised and the data processed using a PET microcomputer. Hard copy could be produced by photographing the trace on the videodensitometer, by photographing a suitable form of rendering of the digitised data on the PET screen, through the use of an X-Y plotter or through the use of a teleprinter system.

The colour video slicing, videodensitometric, and picture digitisation, equipment is depicted in Fig. 7. The video signal from the Link Electronics black and white CCTV (A) is fed via the video slicer and PAL colour encoder (B) to the colour video monitor (C). The camera video signal is also fed to the raster analyser for line selection (D) and the video strobe unit (E). Storage oscilloscope display (F) of a single line can be monitored, while waveform digitisation with the A/D converter (G) allows processing of the selected portion of an image with the PET microcomputer (H). The Computhink floppy disk system is seen to the right of the PET, behind which (not visible) is the X-Y plotter for producing single-line trace hard copy. The teleprinter (not shown) is employed for producing the equivalent hard copy printout of the PET screen image display.

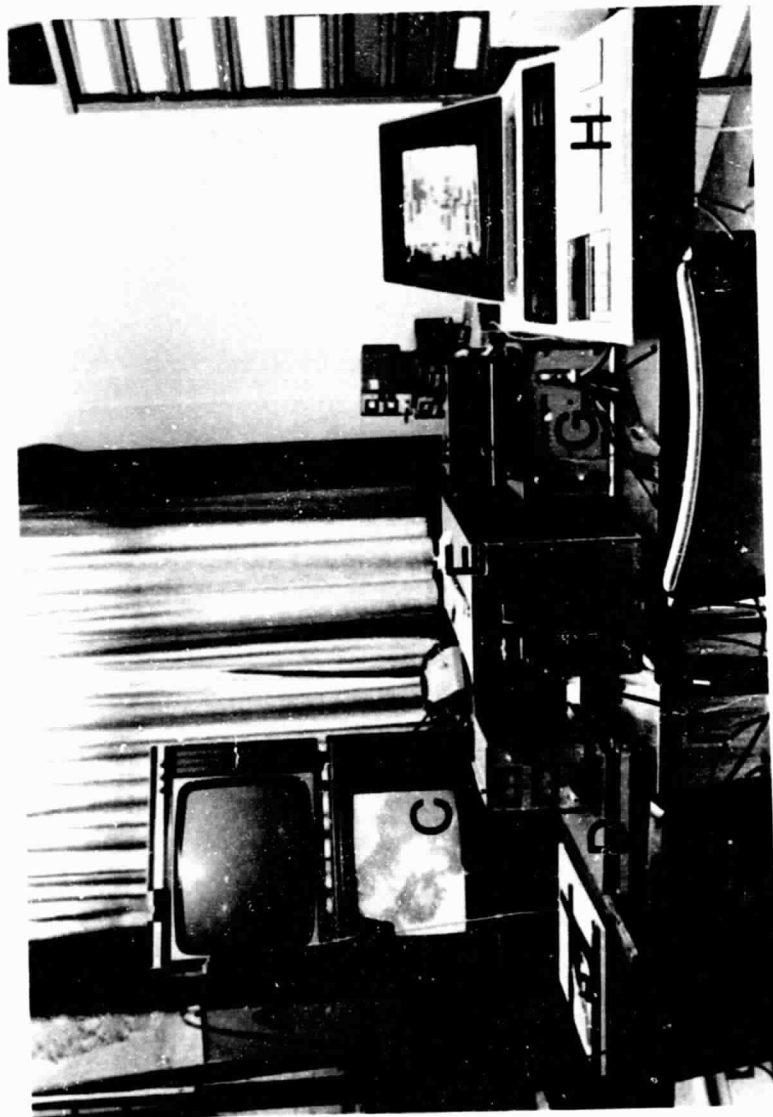


Fig. 7 Video Processing Equipment used in the Project

This equipment allowed us to survey large oceanic areas represented on either transparencies or prints. However, prints were difficult to view in this way because it was not easy to achieve uniform illumination across the whole of a print. Therefore, transparencies were normally used for video synoptic studies (whereas prints were useful for visual synopses). The transparencies were illuminated by fluorescent strip lights diffused by a ground glass screen. TV camera shading was minimised by using a silicon diode camera tube.

When oceanic anomalies were noticed in the synoptic view in false colour, an assessment as to whether they were natural phenomena (such as thermal fronts), or possible man-made features, was made. In the latter case, detailed line profiles were examined, using the videodensitometer. Quantitative video line processing with corrections for camera shading and uneven illumination was readily achieved through the use of the PET microcomputer and floppy disk system.

In order to facilitate the examination of small areas of the images, a microscope was introduced between the transparency stage and the CTV camera. This subsystem was found to produce a satisfyingly flat illumination field in the case of the examination of details.

Further reference to the video processing system will be found on pages 8-14, 21-25, and 29-30.

(B) Outdoor Simulator of HCMM Satellite/Oil Spill System

An outdoor simulator (Fig. 3) using two, one-metre diameter PVC tanks to hold, respectively, water and oil-on-water, those tanks being viewed by IR and visible sensors held aloft by means of a gantry capable of rotation in the plane of the daytime HCMM satellite passes, was designed by the P.I. and constructed by his technical support team to test the capability of selected instruments to discriminate between the water, and the oily, surface. The tanks were filled with identical volumes of tap water and a film of North Sea oil was introduced to one of them. The oil was crude terminal oil from the Ekofisk platform of

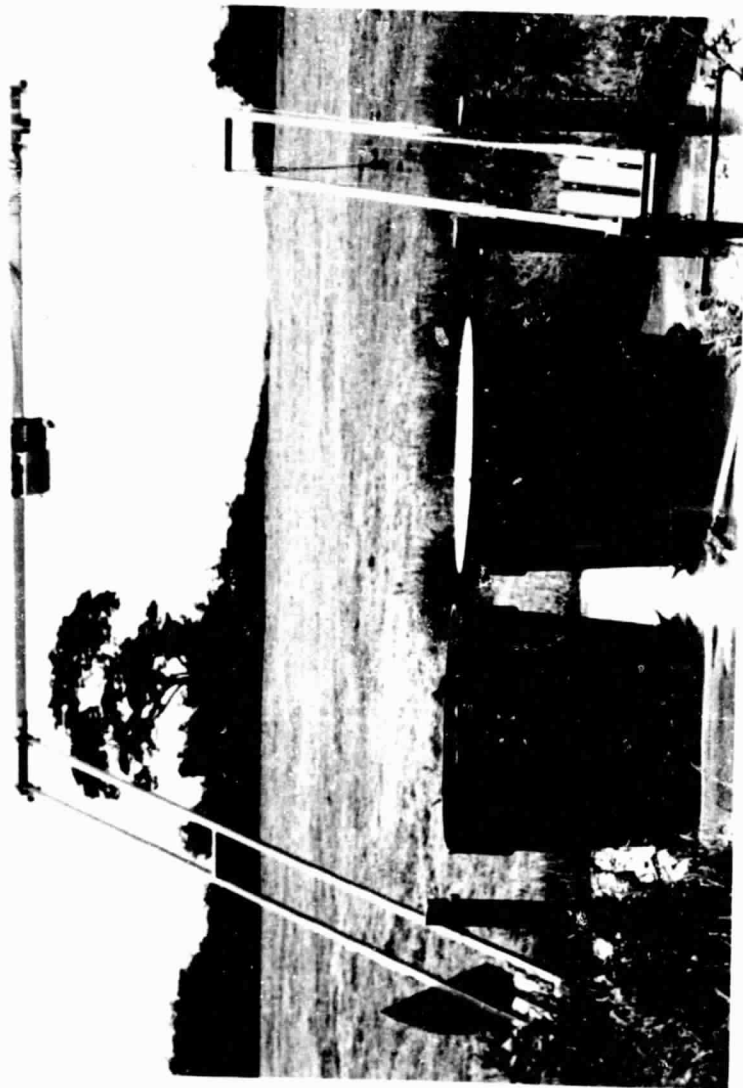


Fig. 8 The Outdoor Simulator used in the Project

Norpipe Petroleum Ltd. (U.K.). It was noted that the only difference between the terminal oil and the rig oil was that the former had lost its high volatile component. In the case of an oil spill in the sea this component would vaporise and dissipate almost immediately; so the present experiments would be relevant to the spill situation.

A support plate holding two, 35 mm cameras and an Eltek I.R. sensor and chopper could be moved along the horizontal arm of the gantry. The camera shutters were actuated remotely by use of pneumatic lines. The tanks could be filled and emptied, as required, using a water-suction pump.

In the first set of experiments, the surface and bulk temperatures of each of the liquid systems were monitored directly using miniaturised Pt-resistance thermometer probes supported by passing the leads through flexible aluminium tubing which was itself supported from the rims of the tanks. Two temperature probes measured the surface layer (1 mm thick) in each tank (one surface layer being of oil and the other of water) and two probes measured the temperature of the underlying water at a depth of a few centimetres in each tank. The actual temperatures at these four points were displayed sequentially as four digits on a Farnell Instruments DRT 2 Unit, the readout from a given probe being selected by means of a Cropico, Ltd., low contact resistance switch. Experiments commenced after both tanksful had been left long enough to ensure that a condition of mutual equality of bulk water temperature pertained. A real temperature difference of the order of 1 degree was determined, the oil surface presenting the higher temperature in daytime conditions.

Remote sensing tests were then run using the gantry subsystem. One camera was loaded with panchromatic film, the other with film sensitized to respond over the optical IR band 670-880 nm. A phase sensitive detector, used to monitor the signal from the IR sensor/chopper assembly, was housed in a nearby laboratory.

The gantry carrying the sensors was rotated in 15 degree increments of elevation and, after each increment, IR readings (measured in millivolts) were taken from the gauge of the PSD and, at the same time, control photographs were secured using remote control shutter release pneumatic lines. For each elevation of the gantry the tanks were observed in rapid sequence, by sliding the sensor carriage along the horizontal track of the gantry, in order to achieve equality, or near equality, of environmental factors such as solar altitude and atmospheric extinction.

These experiments tended to confirm those using PRT sensors, in that the oil surface was generally warmer than the unpolluted water surface (see Table 1). Moreover, it was noticed that, whenever the wind over the tanks increased (even in short gusts), the PSD registered changes which indicated that the temperature of the oil surface increased even more above that of the water surface.

Table 1: Specimen of Outdoor Simulator Results

Elevation/°	Readings on PSD/mV		Difference/mV
	Sensor above water	Sensor above oil	
30	1.51	1.84	0.33
45	1.72	2.18	0.46
NW 60	1.47	2.07	0.60
75	1.20	1.80	0.60
90	0.97	1.64	0.67
75	0.90	1.67	0.77
60	1.10	2.11	1.01
SE 45	1.42	2.65	1.23
30	1.89	2.95	1.06

Notes

Larger PSD readings correspond to higher temperatures.

The altitude of the Sun was 57° and the sky was cloud free.

(C) Indoor Simulator: Effects of Changes in the Ambient Temperature and Humidity

Because of the need to control the immediate environment around the tanks a small-scale version of the simulator was developed for use in the laboratory. Here, surface temperature measurements were taken, using PRT's, at times of different ambient (room) temperature and relative humidity.

Specifically, the aim of the indoor simulation experiment was to determine, for given environmental conditions, the surface temperature of a given volume, v , of North Sea oil overlying a given volume, V of water and to compare the observed temperature of the oil with that of a surface of uncontaminated water of volume $V + v$ (where $V \gg v$). By conducting such an experiment it is possible to assess the likely response of the HCMM heat sensors to an oil slick at sea.

Our earliest experiment in the laboratory made use of a pyroelectric radiometer and phase-sensitive detector to compare the heat flux deriving, respectively, from the surface of a volume, V , of water, and a surface film of crude oil covering a second volume V of water. The surface oil remained at a sensibly higher temperature than that of the comparison water surface.

In an attempt to discover the reasons for this difference it was decided to examine the following hypotheses:-

- H1 - The water-with-oil (System A) and water (System B) systems were not in identical thermal situations in thermal equilibrium;
- H2 - System A alone was exhibiting a radiation balance regime similar to a "greenhouse effect";
- H3 - System B was being cooled, by evaporation, faster than System A;
- H4 - The surface temperature of System A depended on the thickness of the oil layer.

Accordingly, the equipment was improved (Fig. 9) in order to (a) minimise differences in the initial thermal conditions of each of the systems; and (b) introduce direct temperature read-

Temperature Sensing Points

- 1,5,6. air
- 2,4. surface of water
- 3. bulk of water
- 7,9. surface of oil layer
- 8. water beneath oil

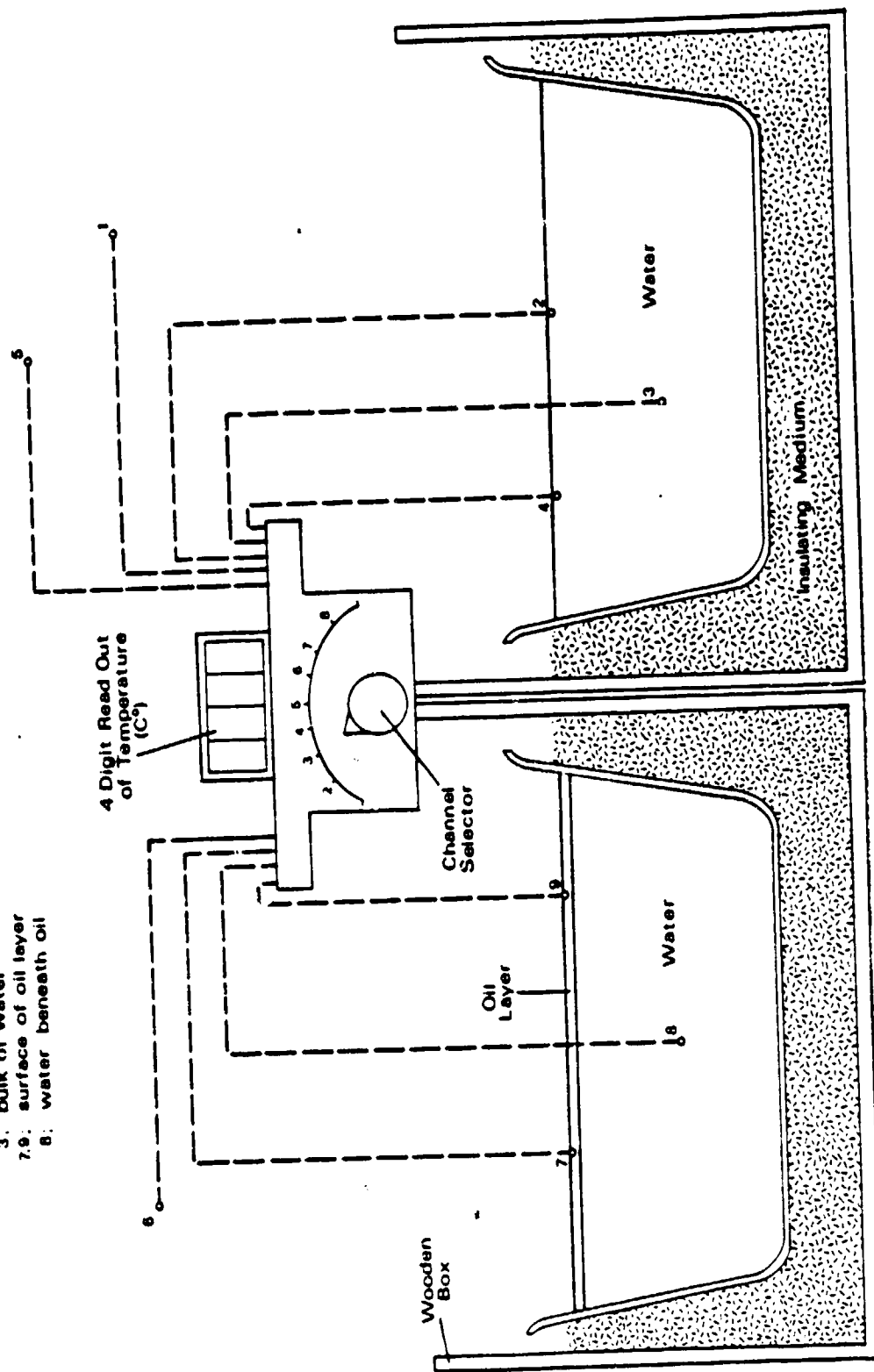


Fig. 9 The Indoor Simulator used in the Project.

out at a few selected points in, and above, each system. Then the liquid systems were carefully re-established as follows. System A was prepared by measuring 2.8 litres of tap water at room temperature and introducing it to a polythene bowl. This water was covered (in the first instance) by 400 cm³ of oil, at room temperature, to give an overall depth of the fluids of 6 cm. System B was prepared by measuring 3.2 litres of tap water at room temperature and introducing it to a polythene bowl which was virtually identical to the first. The oil of System A was crude terminal oil from the Ekofisk Field.

Each polythene bowl was embedded in a medium of PVC packing chips contained in a thick-walled wooden box and the boxes were placed in lateral contact. The bottoms and sides of the bowls were thus effectively insulated from the surroundings; and the walls of the boxes rose well above the liquid surfaces so as to minimise draughts and maintain similar ambient conditions above each system. A wooden gantry was mounted over the top of the boxes in a position of symmetry with respect to the two polythene bowls. Miniaturised Pt-resistance temperature probes were supported by this gantry and placed in strategic positions (the points 1 ... 9, specified in Fig. 9). The temperatures at these stations were monitored following the method (page 39) employed in the case of the outdoor simulator.

In this and subsequent experiments, the equipment was left to attain an equilibrium state before measurements were commenced. It was found that an interval of one day was normally sufficient for this purpose. In order to test H4, the thickness of the oil layer was changed several times over the range ~ 1 mm to 1.9 cm.

Table 2 shows results of a representative run at sensibly constant, and low, relative humidity (< 10%) but with varying oil layer thickness.

Care was taken to ensure that the platinum resistance thermometer elements could be held rigidly in their appropriate

Table 2: Indoor Simulator Results in the case of Low Relative Humidity (< 10%)
and Different Oil Layer Thickness

Thickness of oil layer	0.02 cm	Left overnight 0.02 cm	0.1 cm	0.75 cm	1.13 cm	1.50 cm	1.88 cm
Oil Surface (7, 9) Mean T °C	20.40	21.15	21.85	22.15	19.75	21.00	22.05
Water Surface (2, 4) Mean T °C	19.55	20.20	20.70	20.80	18.1	19.20	20.35
Bulk Water (8) Under Oil Mean T °C	20.35	21.05	21.45	21.95	19.80	20.65	21.25
Bulk Water, Mean T °C (3)	19.60	20.15	20.65	20.70	18.15	19.15	20.00
Air (1, 5, 6) Mean T °C	21.50	22.35	22.90	23.35	20.35	22.00	23.50
Difference in Surface T °C Oil-Water	0.85	0.95	1.15	1.25	1.65	1.80	1.60
Difference in Bulk Water and Water Surface, T °C	0.80	0.75	0.65	1.15	1.70	1.45	0.90
T °C Difference (Bulk water under oil - Bulk Water)	0.75	0.90	0.80	1.25	1.65	1.50	1.25

positions by enclosing the leads in soft aluminium tubing, which was bent to the required shape *in situ*. Evaporated water in the water-only vessel was topped up at the start of an experimental run. Equilibrium temperatures of each probe were measured sequentially, using the rotary switch which was fixed on the rigid wooden gantry along with the digital electronic thermometer unit. During these experiments, the probes were left in position, only minor adjustments being made as required.

It is evident from Table 2 that there is little change in the difference between the oil layer surface temperature and that of the water surface. The actual temperature difference is about one Centigrade degree in all cases, the oil surface being consistently the warmer.

The relative contributions of H2 and H3 were assessed by changing the ambient humidity using a temperature controlled water bath in the closed laboratory. A whirling hygrometer was used to measure the relative humidity of the air in the laboratory for a range of equilibrium conditions. Relative humidities covering the range of from < 10% to 65% were generated in this manner.

Table 3 relates the results found when the relative humidity was varied at constant oil layer thickness. There is a noticeable trend towards smaller surface temperature differences as RH increases; and there is a tendency for the temperature difference to level off at about 50% RH.

It will be noted that the difference between the surface and the bulk temperatures of the water-only bath also decreases with increasing RH, as does the temperature difference between the bulk water-under-oil and bulk water (only) in their respective baths.

In these experiments, the observational evidence suggests that the main contribution responsible for the surface temperature difference is the permitted evaporation of water at the water-only bath surface, an effect which would be increasingly important at low RH.

Increasing the oil-layer thickness has relatively little effect in cases of thickness in excess of 1-2 mm. However, it is expected that, under calm conditions in the open sea, the surface temperature of isolated aggregates of heavy crude oil would be sensitive to thermal radiation balance.

Table 3: Indoor Simulator Results in the case of Constant Oil Layer Thickness (1.88 cm) and Different Values of Relative Humidity

Relative Humidity	< 10%	20%	50%	65%	< 10%*
Oil Surface (7, 9) Mean T °C	24.10	23.95	25.15	25.95	27.90
Water Surface (2, 4) Mean T °C	22.20	22.50	24.00	24.75	24.95
Bulk Water (8) Under Oil Mean T °C	24.30	23.50	24.40	25.05	25.30
Bulk Water, Mean T °C (3)	22.20	22.30	23.65	24.4	23.90
Air (1, 5, 6) Mean T °C	23.90	25.30	26.20	26.80	33.30
Difference in Surface T °C Oil-Water	1.90	1.45	1.15	1.20	2.95
Difference in Bulk Water and Water Surface, T °C	2.10	1.00	0.40	0.20	0.35
T °C Difference (Bulk Water Under Oil - Bulk Water)	2.10	1.20	0.75	0.55	1.4

* Ware room: repeat after 54 hours.

(D) Wind Tunnel: Effects of Wind Velocity and Temperature

In certain of the outdoor simulator experiments (*U. supra*) it was observed that there was, at a given instant, a correlation between wind velocity and the temperature of the oil surface: as the wind velocity increased, so did the temperature of the oil.

In order to investigate this effect, a low velocity wind tunnel (Fig. 10) with a working section of about 0.074 m^2 was adapted to our needs by removing part of the false floor and lowering two, adjacent plastic trays into the cavity in such a way that their rims were level with those parts of the false floor which were left, *in situ*, both immediately upstream, and immediately downstream, of the trays.

Four circular apertures were cut in the base of each of the plastic trays and each aperture was filled and sealed with a rubber bung carrying the leads of a PRT probe which entered one of the plastic trays (Fig. 11). The PRT leads were fed through holes, drilled in the base of the wind tunnel and corresponding to the apertures in which the bungs were inserted, to the 4-digit Farnell temperature recorder and channel selector illustrated diagrammatically in Fig. 9. Each tray was filled to the brim with a measured volume (3.0 l) of tap water and allowed to attain thermal equilibrium.

Two temperature sensor elements were arranged to lie just in the upper 2 mm of liquid in each reservoir and two in the bulk of the liquid (water) in each reservoir. These sensors were offset from the longitudinal axis of the wind tunnel by amounts which minimised the effect of the presence of one probe on the reading of another probe. A ninth temperature sensor was used to measure air temperature in the boundary layer immediately downstream of the tanks (Fig. 11).

The fan of the wind tunnel was fed from the mains through a Forster Voltage Regulator which was calibrated in terms of wind speed using an ETA 3000 hot wire anemometer manufactured by Airflow Developments Ltd. Wind speeds of from 0.5 to 10 m s^{-1} were generated just above the surfaces of the fluids in the tanks: this range embraced the critical value of wind

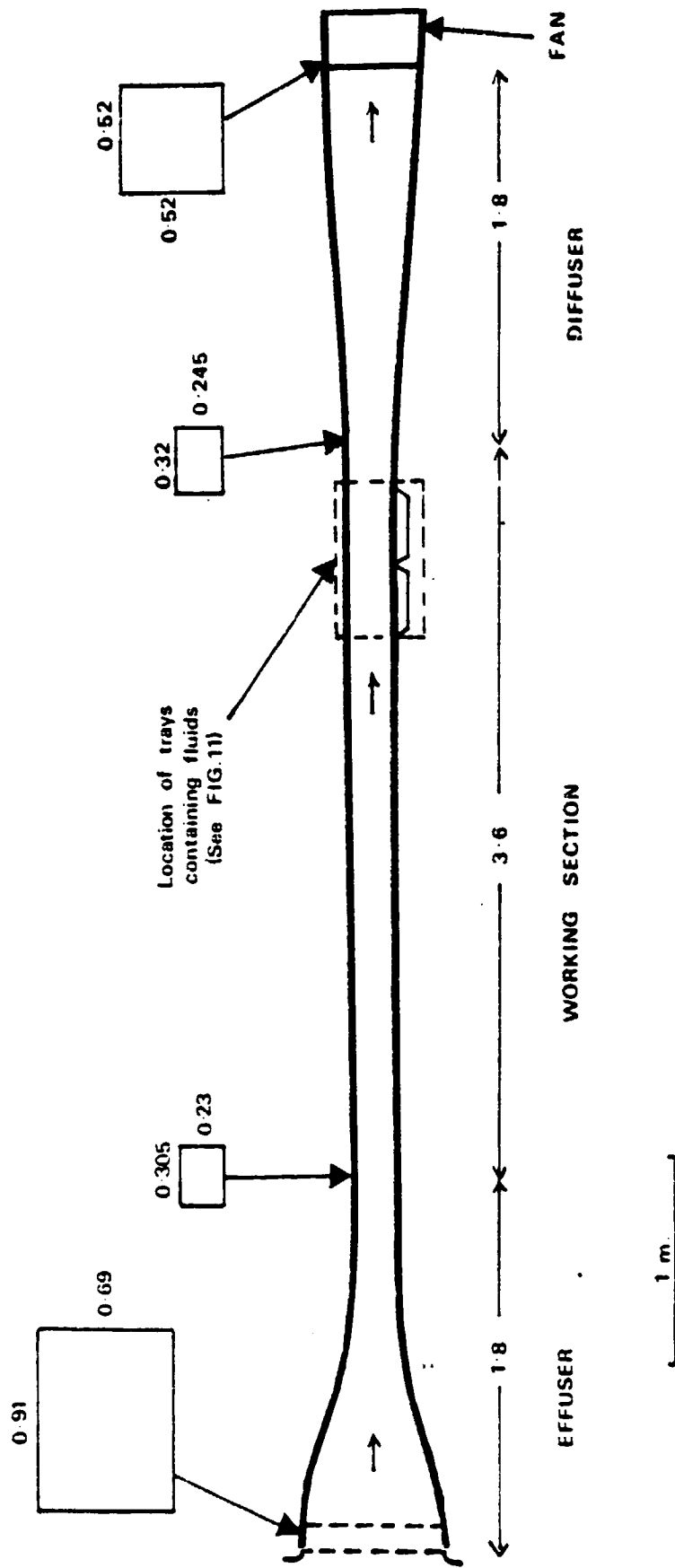
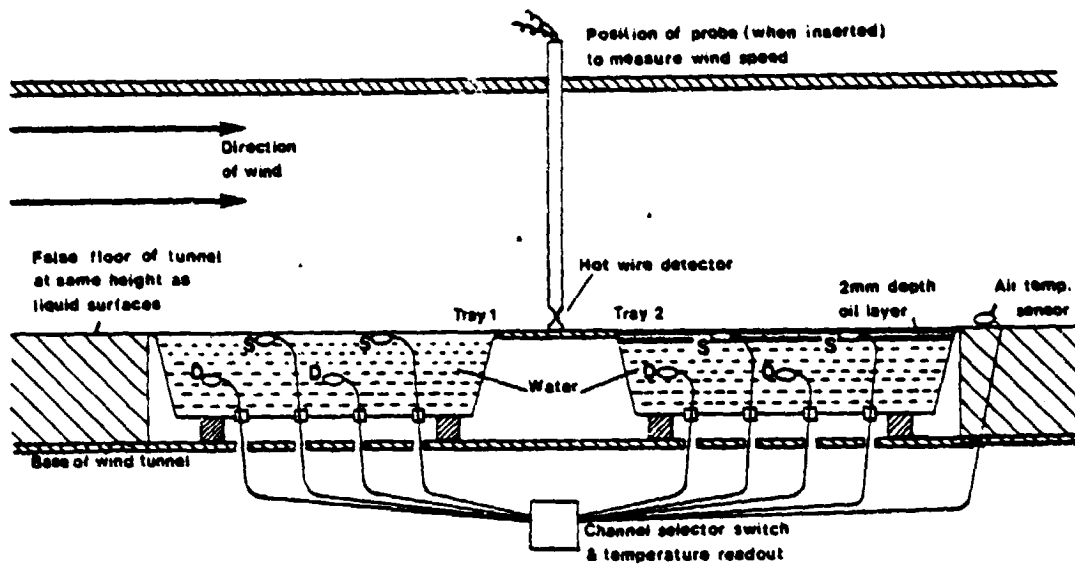
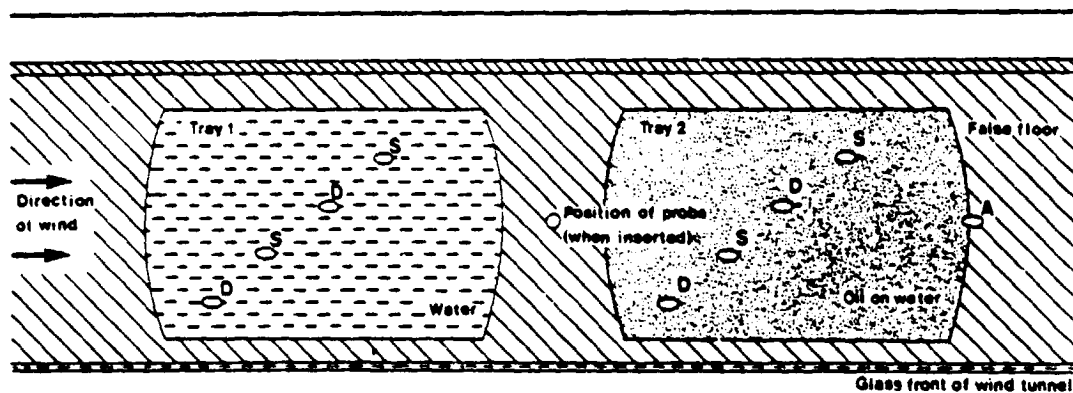


Fig. 10 Longitudinal Section Through the Low Velocity Wind Tunnel used in the Project
(All dimensions are in metres)

Side Elevation



Plan



Temperature Sensors

- D Sensor in bulk of water
- S Sensor in surface of water or oil
- A Sensor in air boundary layer

Fig. 11 Diagrammatic representation of oil slick simulation in the Wind Tunnel, showing locations of the nine temperature sensors.

speed at which a transition from laminar to turbulent flow might be expected. In practice, the upper limit of wind speed was 8 m s^{-1} , since above this value the water tended to spill over the leeward edge of its container.

A volume of 125 ml of water was removed from one of the trays and the same volume of crude oil added, by pipette, in order to produce an oil layer exactly 2.0 mm thick: this was also the diameter of one of the cylindrical PRT sensors. For pre-selected wind speeds (Figs. 12 and 13) the temperatures measured by the nine sensors were then read at given time intervals over a period long enough to determine the approach of each of the two systems to equilibrium.

With the room temperature slightly higher than that of the fluids, tests showed that the oil surface gained heat relative to the unpolluted water surface. This effect increased with increase of wind velocity. The temperature of the air in the wind tunnel relative to the temperature of the water was then increased further, in an attempt to exaggerate the effect already noted, by introducing an electric heater at the air intake end of the tunnel. The general results of these tests, considered to be simulating conditions similar to those applying to the North Sea in summer, are given in Table 4 and are shown graphically in Fig. 12 (for a low wind speed) and Fig. 13 (for a higher wind speed).

In order to investigate the physical consequences of the flow over the tanks of air that was colder than the fluids they contained - an experimental system that might find a close parallel in winter conditions in the North Sea - methods of cooling the air before it reached the tanks in the wind tunnel were first considered. The use of a pack of ice blocks held before the entry effuser of the tunnel in a bag of wire netting was found to be unsatisfactory, experimentally, because of the need for a high replenishment rate of ice. Finally, one submersible heating element was used in each of the tanks (the heaters being identical) in order to raise the temperature of the fluids above that of the air, at room temperature, passing through the tunnel. The degree of heating was controlled by means of a

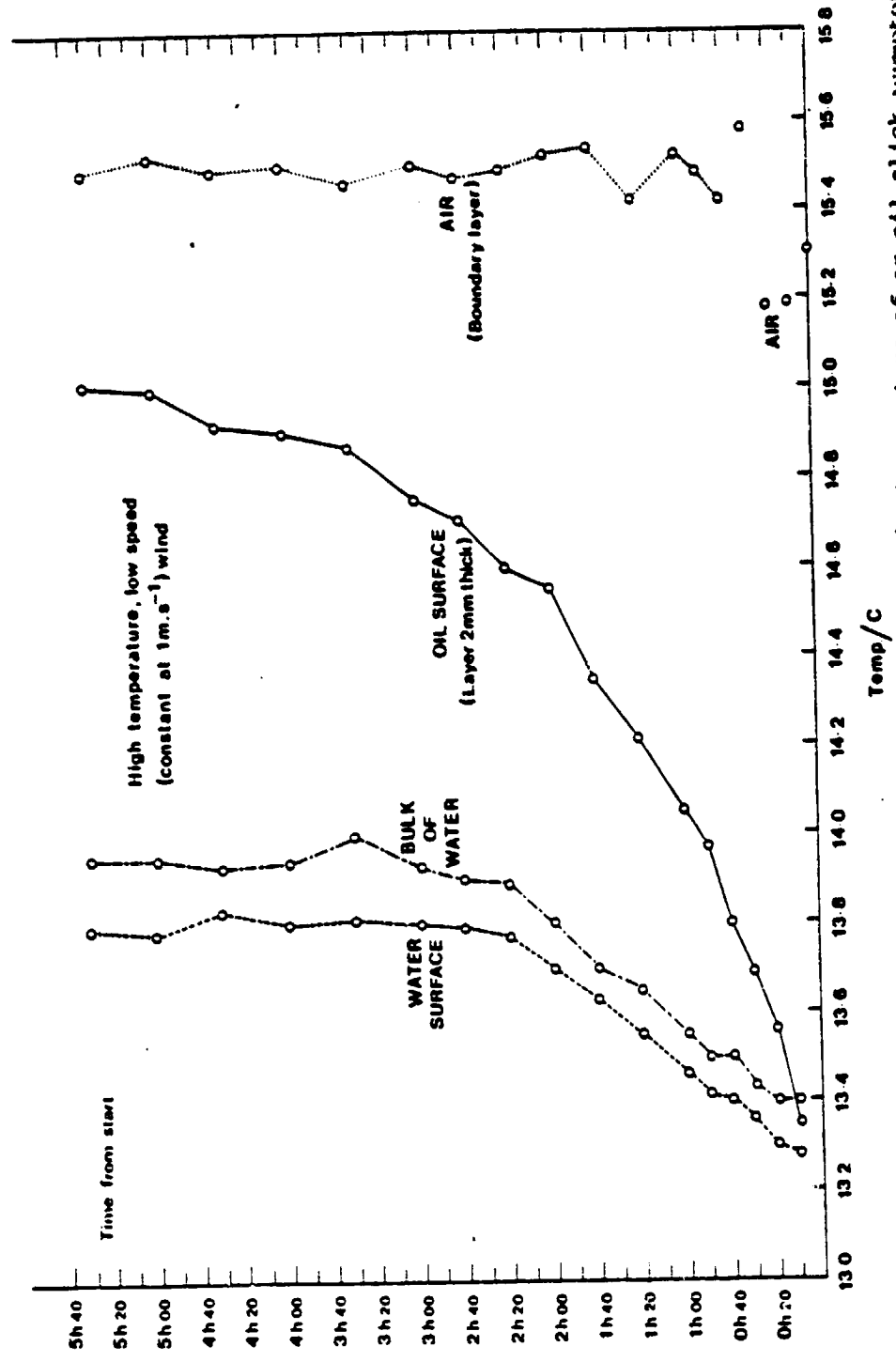


Fig. 12 Graphs illustrating how, in "summer" conditions, the temperature of an oil slick asymptotes at a higher temperature level than that of uncontaminated water under similar environmental conditions with a wind blowing at 1 m s^{-1} .

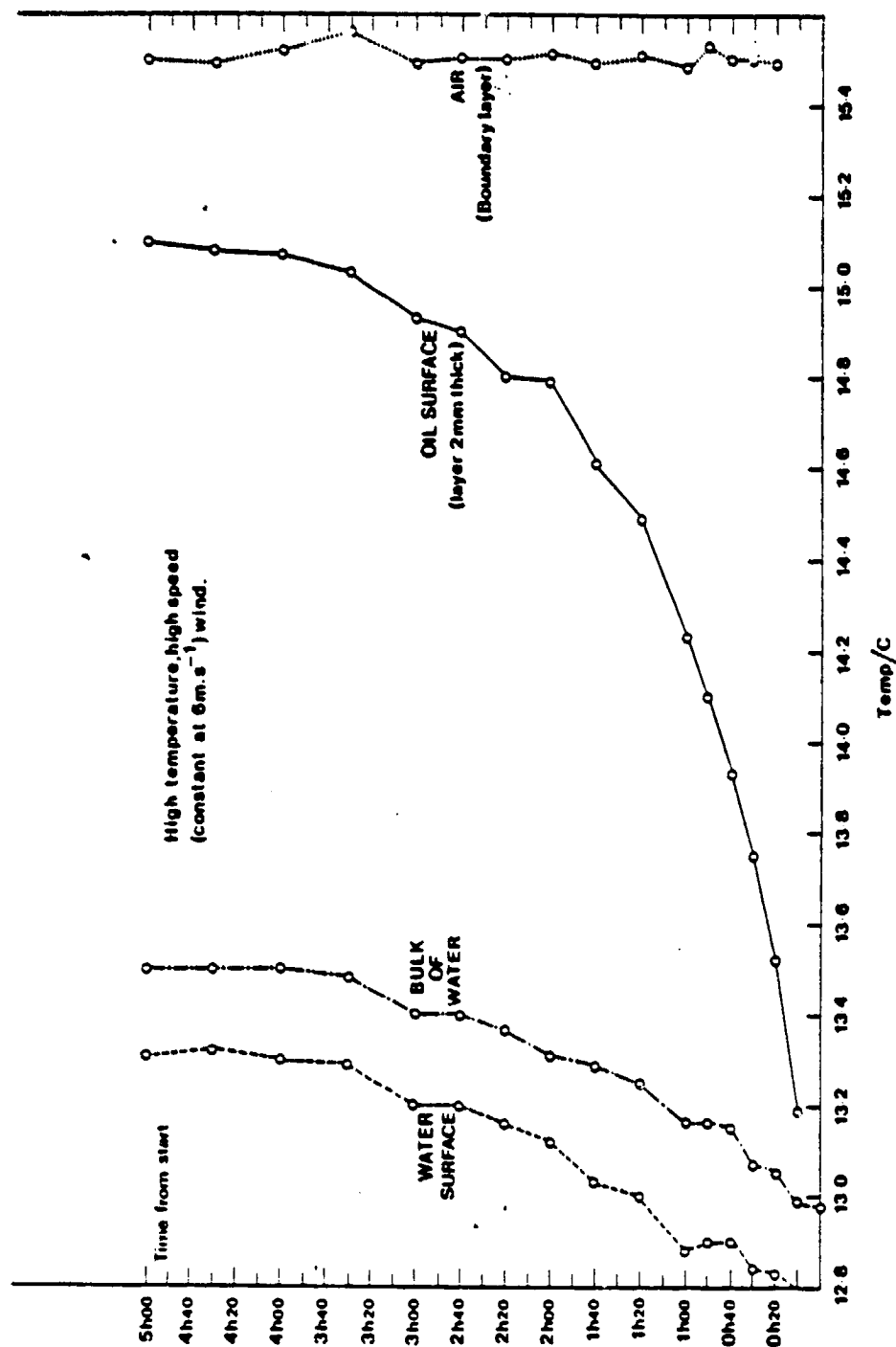


Fig. 13 Graphs illustrating how, in "summer" conditions, the temperature of an oil slick asymptotes at a still higher temperature (cf Fig. 12) than that of uncontaminated water under similar environmental conditions with a wind blowing at 6 m s^{-1} .

Table 4: Wind Tunnel Results: "Summer" Conditions

Wind velocity m s ⁻¹	Time after oil spillage	Water surface temp/C	Oil surface temp/C	Tunnel air temp/C
1.0	<u>h</u> <u>m</u>			
	10	13.28	13.35	15.2
	20	13.30	13.56	15.2
	30	13.36	13.69	15.6
	40	13.40	13.80	15.4
	50	13.41	13.97	15.5
	1 00	13.46	14.05	15.5
	1 20	13.55	14.21	15.4
	1 40	13.63	14.35	15.5
	2 00	13.70	14.55	15.5
	2 20	13.77	14.60	15.5
	2 40	13.79	14.70	15.5
	3 00	13.80	14.75	15.5
	3 30	13.81	14.87	15.5
	4 00	13.80	14.90	15.5
	4 30	13.83	14.92	15.5
	5 00	13.78	15.00	15.5
	5 30	13.79	15.01	15.5
6.0	10	12.79	13.19	15.4
	20	12.83	13.52	15.5
	30	12.84	13.75	15.5
	40	12.90	13.93	15.5
	50	12.90	14.10	15.5
	1 00	12.88	14.23	15.5
	1 20	13.00	14.49	15.5
	1 40	13.03	14.61	15.5
	2 00	13.12	14.79	15.5
	2 20	13.16	14.80	15.5
	2 40	13.20	14.90	15.5
	3 00	13.20	14.93	15.5
	3 30	13.29	15.03	15.6
	4 00	13.30	15.07	15.5
	4 30	13.32	15.08	15.5
	5 00	13.31	15.10	15.5

submerged thermostat. Readings of the PRT outputs were taken, as before, except that the records kept related to the temperatures pertaining after convective motions resulting from the heat sources in the tanks had dissipated. Thus, all the readings used to generate the final results were taken, each time, some 10 minutes after the heaters had been switched off.

Qualitatively, the results for "winter" conditions were similar to those for "summer" conditions (Figs. 12 and 13): the oil layer gained heat relative to the surface layer of water, and the difference between these surface temperatures increased with the wind speed over the range 1 to 8 m s⁻¹. It would appear that energy was being transferred from the air to the fluids by the mechanism of viscous dissipation in the fluids.

(A) Processing of Satellite Imagery

HCMM transparencies and QL prints and, in the development of the video processing equipment, imagery from NOAA 5, LANDSAT and TIROS N were scanned visually, sorted and catalogued both manually and on magnetic tape, after coding, for insertion on the PET data file. The coding included information on cloud cover as well as on picture frame identification and date. The useful imagery was then subject to semi-quantitative synoptic viewing in order to search for anomalies in marine areas. If defined in terms of apparent grey-level differences between different parts of the marine area in any given image, there were anomalies on most images, seen more readily in false colour. However, the general form, extent and location of most of these anomalies provided a means of judging them as phenomena (such as marine thermal fronts and estuarine deposits or pollutants) other than the effects (thermal and visible) expected of oil slicks. In those cases when these types of general criteria failed, the anomaly in question was enlarged using the microscope/TV camera system and processed quantitatively. Fig. 14 shows the scheme for the handling of all data.

All images which corresponded to dates (-1 day and + 2 days) of reported oil spills were located in the tape file of picture data and were extracted for examination using colour video slicing, videodensitometric profiling and picture digitisation analysis.

The Lannion QL prints covered a larger range of latitude than the NASA transparencies and provided relatively rapid means of assessing, visually, the usefulness of a given pass of the HCMM satellite in regard to the sea areas around the U.K. The NASA transparencies proved best for false colour synopses and for detailed regional work of a more quantitative nature. Of the transparencies, the D thermal IR images proved to be the most useful, particularly the positive transparencies.

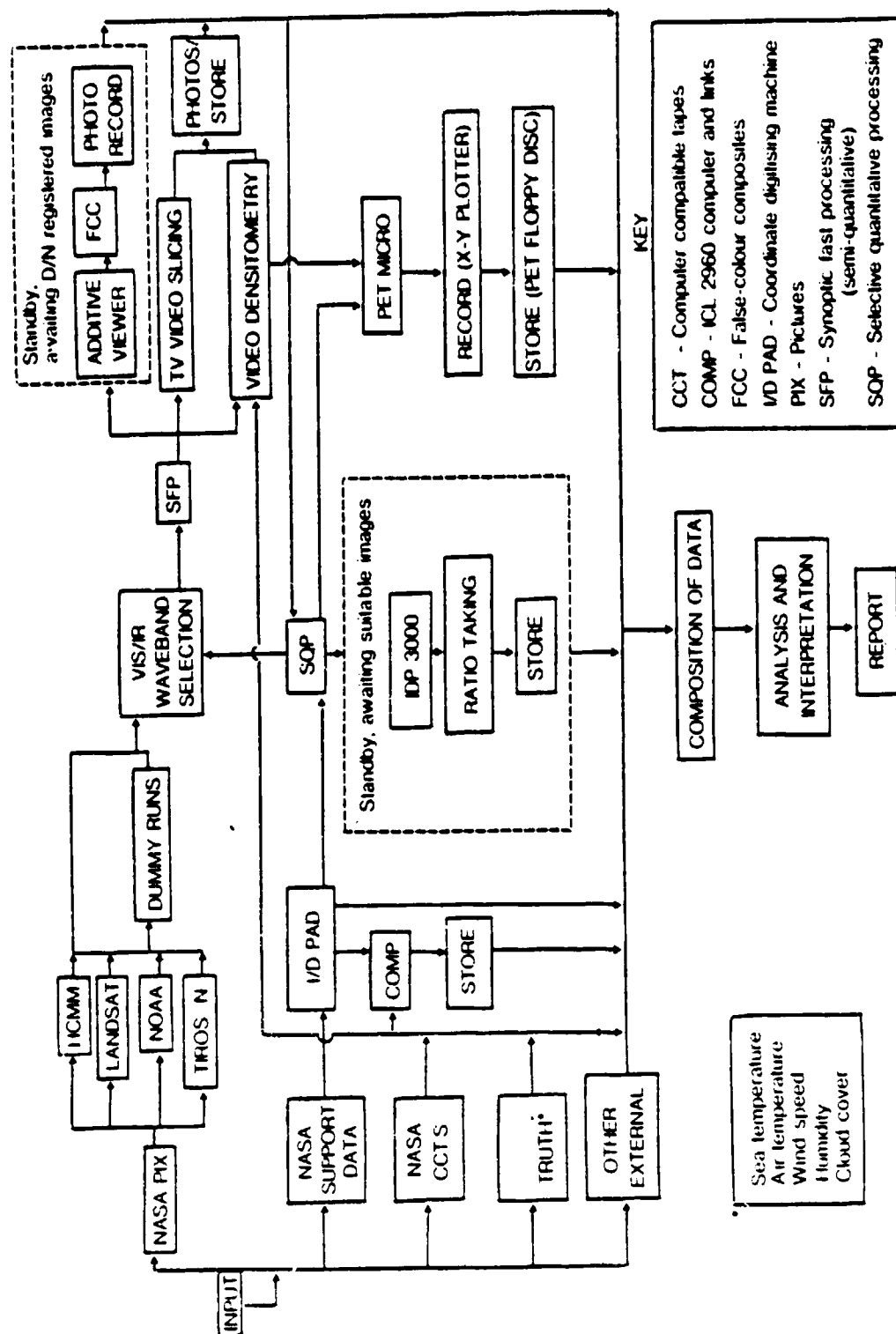


Fig. 14 Data Handling Flow Diagram

(B) Mapping from Satellite Imagery

Computer routines for the preparation of maps of oil slicks from geographical data such as the map co-ordinates of recognisable coastline features on a HCMH image were prepared by R.J. Fryer. Full details of these routines are given in Appendix A.

(C) Recovery and Use of Sea Truth

A survey of sources of sea truth was made by the P.I. who concluded that, although there were a number of special organisations willing to provide a variety of data relating to limited sea areas, the most generally useful data would derive from the Meteorological Office (Department METO 12c) at Bracknell, England. These data may be split into (a) Ice Chart five-day means (which, tests have shown, are more numerous than all other data); (b) data from ships using Code FM21-V; (c) bathymetric data (Code FM63-V) and (d) British Light Vessels data. The data provided range through parameters such as sea surface temperature, cloud amount and type, weather, visibility, surface wind speed and direction, and wave height and frequency. Sea surface temperatures and other sea surface data for four test locations, each corresponding to a specific date and time, were ordered through METO 12c.

In the first area, (Fig. 15) surface temperatures, measured *in situ*, were found to correlate well with the HCMM thermal infra-red brightness data even though the temperatures were five-day means. In Fig. 15, the temperature increases through dark grey to light grey. Specifically, a densitometric profile (Fig. 16) along the marked traverse shows a good correlation with the specified Ice Chart temperatures. However, the Ice Chart data fail to show the prominent and persistent Islay Front feature shown here as a sharp boundary which extends northwards from the N. Ireland coast; and the degree of correlation between the reported sea truth temperatures and the thermal contours of the satellite imagery is poor. The area contained only one SHIP temperature measurement centring on 12Z (midday) of 1978 June 1.

The second area (the southern Shetlands, Fig. 17) was examined for traces of pollution around the coast where there is a concentration of shipping and oil terminal activity. The spindle-shaped cool feature was, however, identified as cloud.

Limiting the sea truth to the time of satellite overpass would have virtually eliminated the input of surface data into the investigation. A compromise was reached in which sea truth



Fig. 15 Test area showing the Islay Front. The horizontal line selects the profile shown in Fig. 16. (HCMM DIR image of 1976, Jun. 1; A-A0036-13490-2).

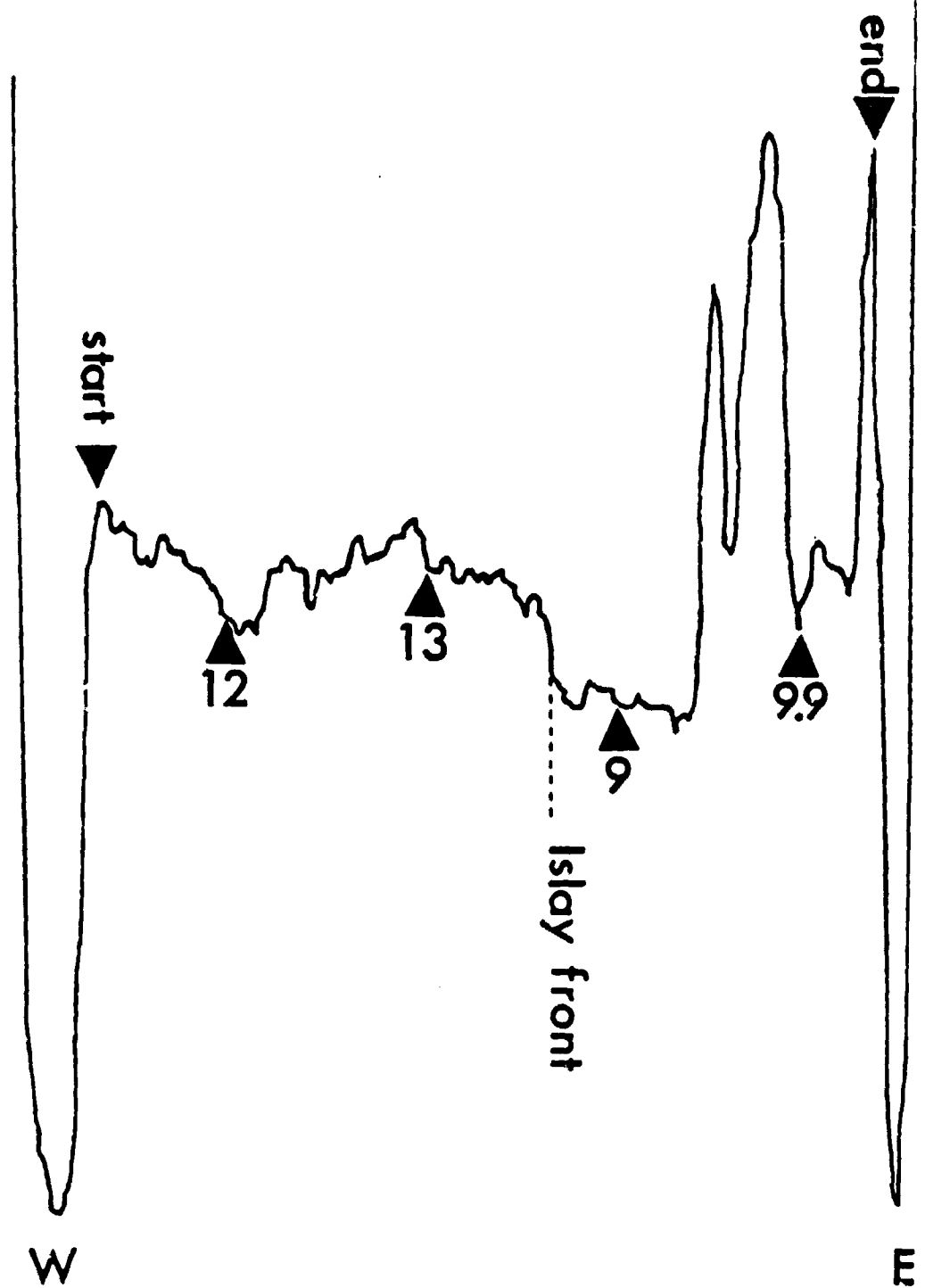


Fig. 16 Densitometric profile showing the thermal IR brightness variation in the HCM image shown in Fig. 15.

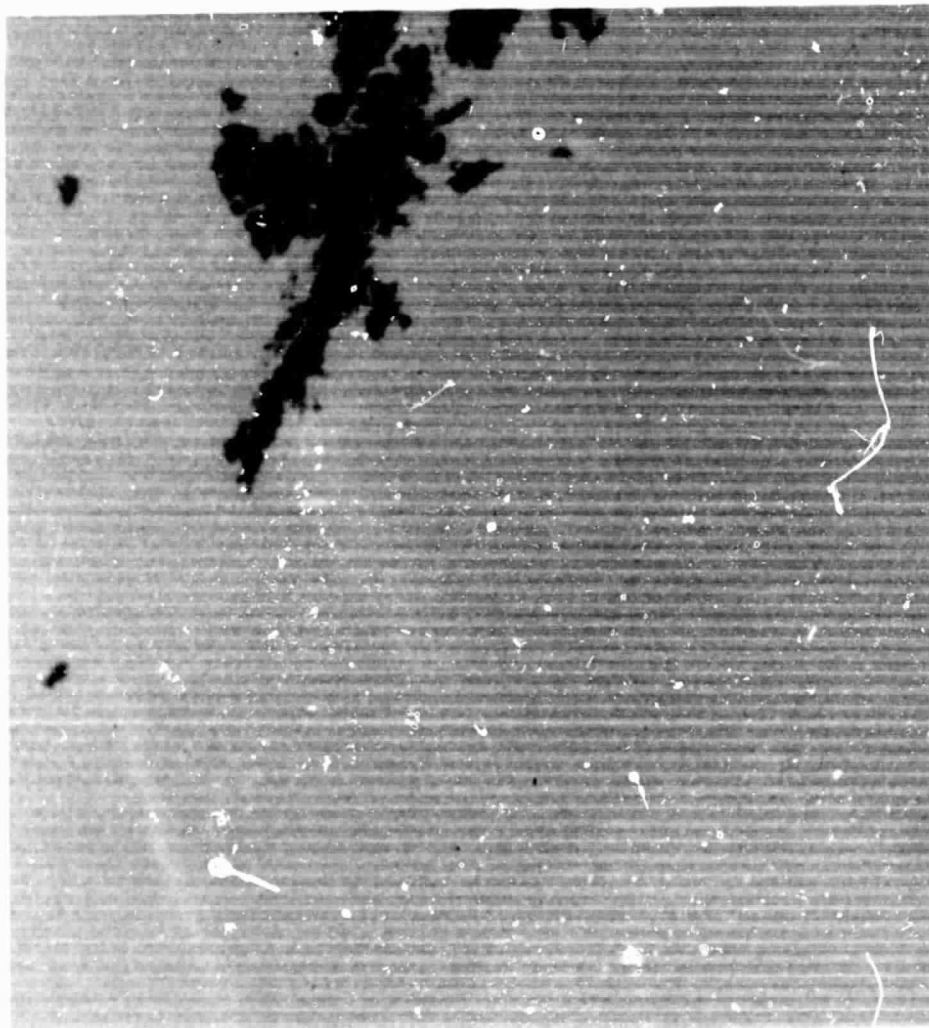


Fig. 17 Test area showing the S. Shetland Islands (HCMM DIR image of 1978, May 10; A-A379-115).

data were extracted over an arbitrary six-hour time interval centring on the time of the acquisition of HCMM imagery by satellite. Even then, the area contained no surface temperature data over the six-hour time interval centring on 12Z of 1978 May 10.

In Figs. 18 and 19 the grey level coding is the reverse of that specified for Figs. 16 and 17. The region demarcated in Fig. 18 by a black rectangular boundary (a marine area off Stavanger, Norway) is shown (Fig. 20) in the uncorrected, digitised display on the PET screen. (The same display is seen recalled from disk-file in Fig. 7). In this demonstration of the technique, the effects of raster lines are evident in both images. Some discrepancies are evident in the two images, which were prepared on different occasions. Particular care was taken to minimise camera shading and uneven illumination while preparing the digitised image, but the effects of image raster lines are clearly seen in the absence of correction.

The area shown in Fig. 18 contained only two SHIP temperatures centring on 12Z of 1978 May 28.

The image of Fig. 18 was taken during the period of the "Eleni V" spill on 1978 May 30; but the picture is dominated by the presence of raster lines present in the original hard copy. This area (Dover Strait and River Thames) contained eight British Light Vessel (BLV) temperature measurements and three SHIP temperature measurements, all centring on 00Z (midnight) of 1978 May 30.

Most of our total area of investigation is without BLV data, which concentrate in the Dover Strait - Thames estuary area and provide temperatures to the nearest whole degree. This may be compared with the one-tenth of one degree temperature data reported on the SHIP coding (but the significance, and usefulness, of this degree of precision is questionable). None of the four test areas contained any BATHY temperatures.

The Ice Chart five day mean temperatures are deduced from the observations made from a stated number of ships within a given square of side one geocentric degree: the sides of the square run parallel, and perpendicular, to parallels of latitude.

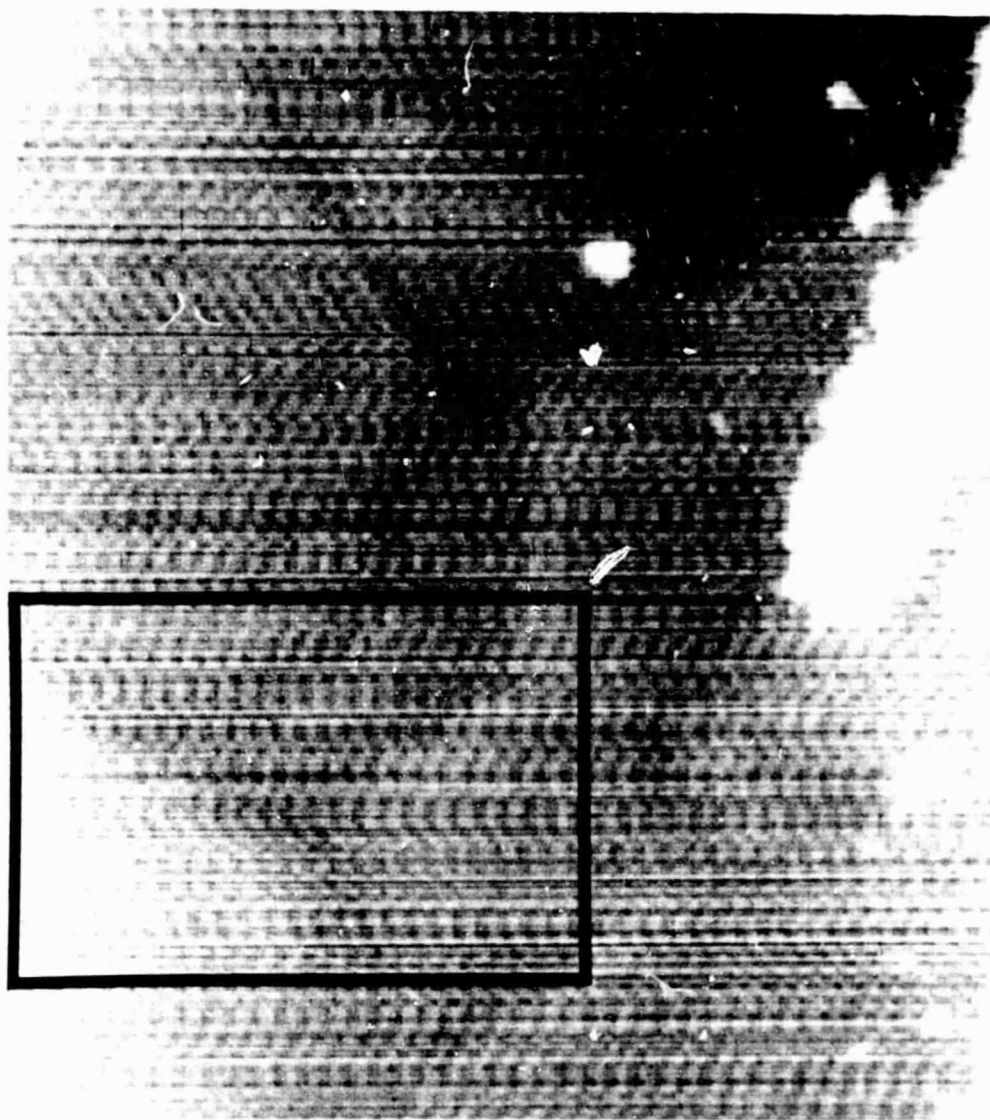


Fig. 18 Test area showing the North Sea to the west of
Norway (HCMM DIR image of 1978, May 28; A-AOO 12-12360-2) .



Fig. 19 Test area showing the Dover Strait and River Thames area (HCMM DIR image of 1978, May 30; A-AC034-13110-2).

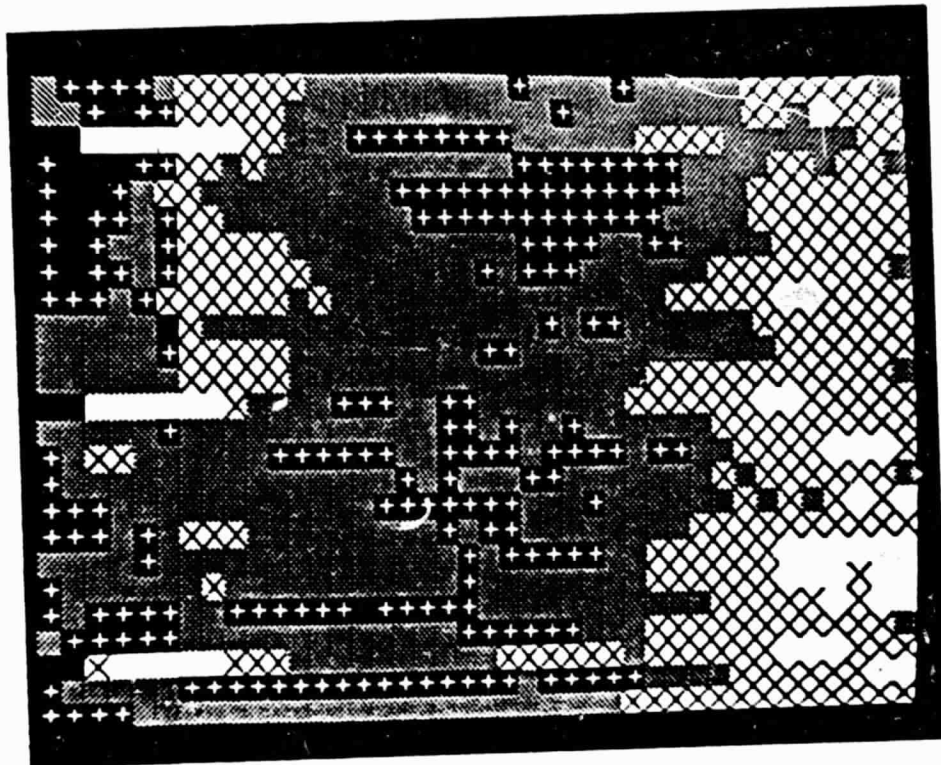


Fig. 20 Digital display on the PET screen.

Correlations of all the sea surface temperature raw data with the Sea Ice Chart five day mean temperatures is mostly good even though the raw data in question refer to the central six-hours of the five day period. In the case of each of the four test areas it is impossible to draw reliable isotherms through the six-hour temperature data. An attempt to construct meaningful isotherms through the relatively densely clustering sea truth points in the area defined by Fig. 19, may, however, be made.

Whereas the Sea Ice Charts are based on BLV and SHIP observations of temperature, the Coastal Ice Charts include additional data such as that received from Icelandic vessels. We conclude that the best sea truth base on which to put the HCMM imagery is that provided by the Coastal Ice Charts, even though they provide only five day means. Data other than temperatures (for example, wind and wave data, visibility, and so on) would still have to originate in BLV reports (not available in most areas) and in sparsely distributed SHIP reports.

(D) Data on Oil Spills

Information on oil spills received from the Department of Trade, London, commonly includes the estimated location of the oil and the length of the slick. The principal input derives from U.K. Coastguards; some data derive from ships and rigs. All data for the period of interest (the calendar years 1978 and 1979) were studied. We also searched the appropriate "Oil Spill Intelligence Reports" published at Boston, Mass.

The most significant of the spill data were abstracted on a card index and the longest spills, or those having the greatest size, were isolated as a basis for searching for anomalies on any corresponding HCMM imagery. It is clear from Fig. 21 that by far the majority of the reported spills were of minor extent. Of the 69 longest oil spills sighted in offshore regions of the U.K. in 1978 and 1979 only a score were in areas which corresponded to imagery acquired for the dates (-1 d, +2 d) in question. No major oil slicks were reported by the Department of Trade in the same period and in the area of investigation.

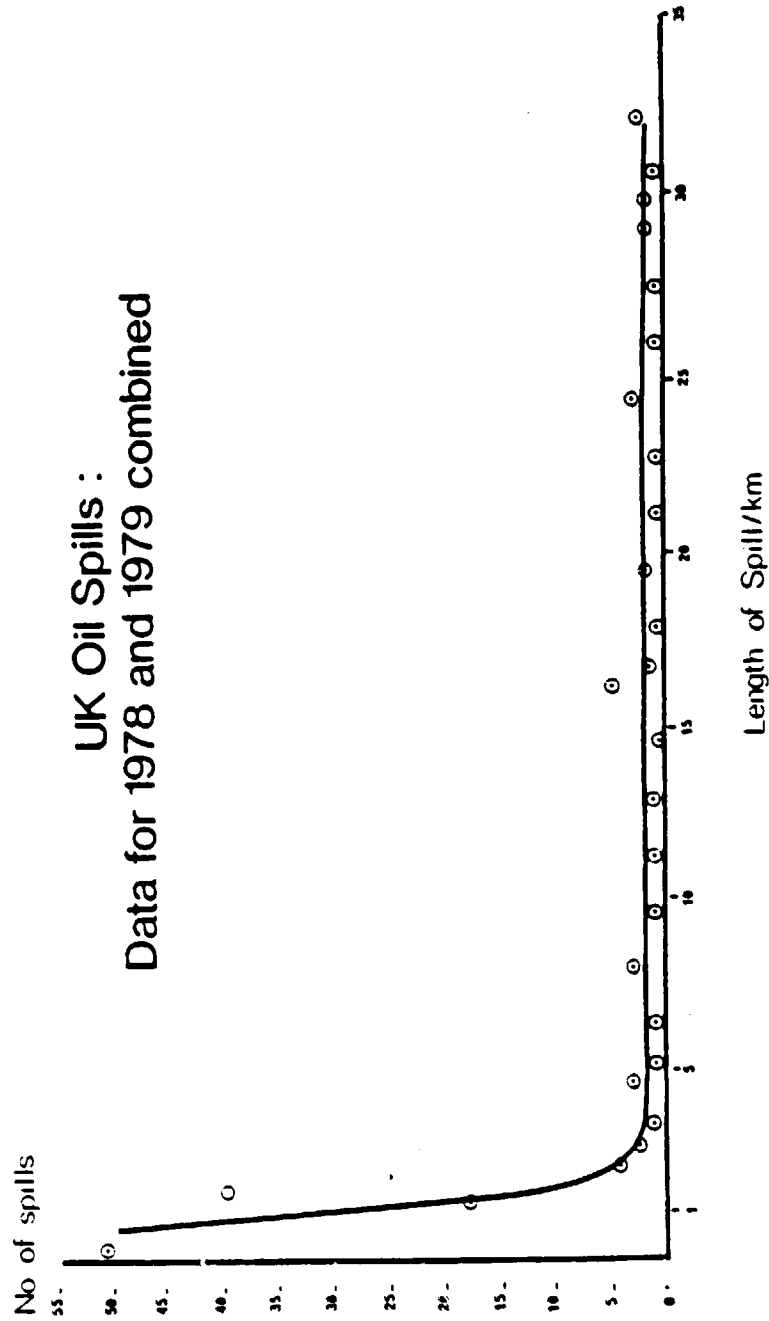


Fig. 21 Frequency of oil spills of a given length: data for seas around the U.K., calendar years 1978 and 1979 combined.

(E) Computer Simulation of the Thermal Regime of an Oil Slick

By developing PET microcomputer routines for the simulation of heat balance regimes in oil slicks, D. Telfer was able to predict that the surface temperature of a slick would increase sharply as the wind over the slick changed its characteristics from those of laminar flow to those of turbulent flow. This result was verified experimentally (see Figs. 12. and 13).

The model represented in Fig. 22 is of an infinite, flat sheet. Forced convective heat transfer between the ambient air and the relatively stationary oil surface layers is most effective under conditions of non-laminar airflow. This occurs at wind-speeds in excess of ~ 4 m/s. At these speeds, the temperature of the oil surface would be expected to follow that of the air more closely than would the temperature of the water, which has the greater thermal conductivity.

This is exemplified in the following two dummy runs involving steady states in which the wind speed is held constant but the air flow is first laminar and then turbulent.

Air Parameters

Wind vel 3 m/s

RI fixed at 200 W/m^2

Reynolds No., $Re \text{ (air)} = 1.2 \times 10^6$

Prandtl No., $Pr \text{ (air)} = 0.71$

Nusselt No., $Nu = 0.037 \times Re^{4/5} \times Pr^{1/3}$ (Turbulent flow)

$Nu = 0.332 \times Re^{1/2} \times Pr^{1/4}$ (Laminar flow)

Thermal Conductivity of air $KA = 2.57 \times 10^{-2} \text{ W/m K}$

Convective loss = $Nu \times KA \times (TS - TA) \text{ W/m}^2$

Radiative Parameters of Oil

Absorptivity, $AB = 0.5$

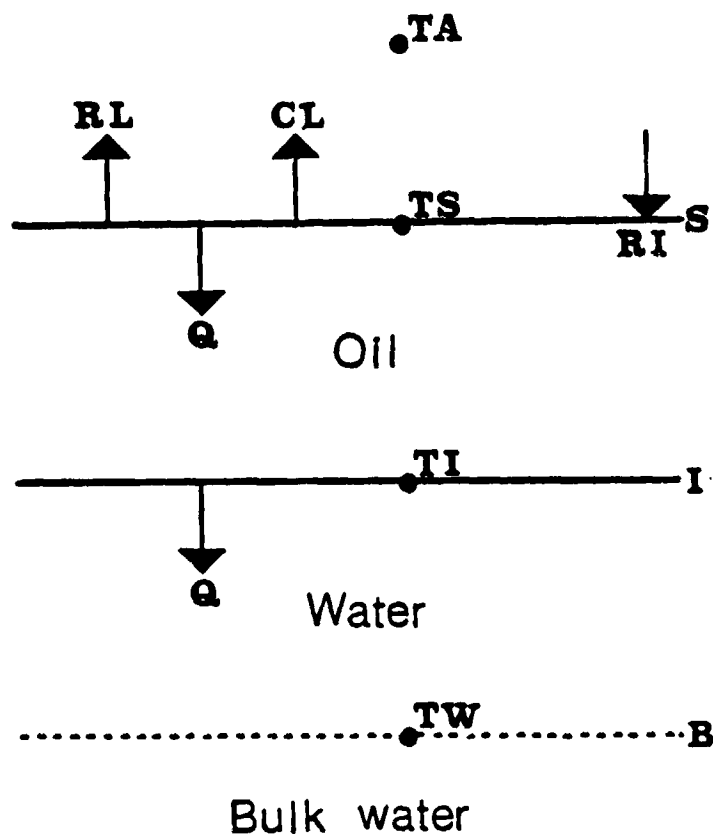
Rate of energy input at surface $QR = AB \times RI = 100 \text{ W/m}^2$

Emissivity, $EM = 0.5$

Radiative loss $RL = EM \times SB \times TS^4 \text{ W/m}^2$

where $SB = \text{Stefan-Boltzmann Const} = 5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$

Nett input at surface $Q = QR - RL - CL \text{ W/m}^2$



Key

- RI = Radiative Input
- RL = Radiative Loss
- CL = Convective Loss
- S = Air/Oil Interface
- I = Oil/Water Interface
- B = Boundary between "surface water" and "bulk water"
- Q = Conductive heat loss from surface S
- TA = Air Temperature
- TS = Oil Surface Temperature
- TI = Temperature at Interface I
- TW = Bulk Water Temperature

Fig. 22 Thermal Regime of an Oil Slick of Infinite Extent.

Conductivity Parameters

a) Oil

Thermal conductivity $KO = 0.138 \text{ W/m K}$

$$Q = KO \times (TS - TL) / XO \text{ W/m}^2$$

where XO = oil layer thickness (m)

b) Water

$KW = 0.6$

$$Q = 0.6 \times (TI - TW) / XW \text{ W/m}^2$$

where XW is the "surface water layer" thickness

Overall transfer coefficient $U (S \rightarrow B) = Q / (TS - TW)$

Thermal resistance $TR = 1/U = XO/KO + XW/KW$

Surface temperature $TS = Q/U + TW \text{ K}$

Interfacial temperature $TI = (TS - TW) / B + TW \text{ K}$

where $B = 1 + \{XO \times KW / (XW \times KO)\}$

Let $XO = 0.1 \text{ m}$ and $XW = 1 \text{ m}$; then $B = 1.4348$

Results

Laminar Flow, 3 m/s

Putting $TW = 283$ and
 $TA = 288$, then
 $TS = 279.44$ and
 $TI = 280.52$

Turbulent Flow, 3 m/s

Putting $TW = 283$ and
 $TA = 288$, then
 $TS = 286.50$ and
 $TI = 285.45$

It is seen that the oil surface temperature follows that of the ambient air more closely in the case of turbulent flow than in the case of laminar flow. This conclusion was also confirmed in our wind tunnel experiments (see Figs. 12 and 13). Clearly it is important to know the prevailing weather conditions in the case of a real event.

2-16/F1-12 RESULTS OF SEARCH FOR THERMAL ANOMALIES IN HCMH IMAGERY

(A) Synoptic Search for Oil Slicks

Transparencies representing the thermal IR response of the HCMH imaging system were keyed geographically to known coastlines, using both the visible channel transparencies and the Lannion QL positive prints. All the "useful" imagery remaining in the inventory after the rejection of (a) poor frames (too noisy, too cloudy, too small a marine area), (b) frames which showed major oceanic thermal fronts and associated thermal structure of a major and regular nature, and (c) frames which, *inter alia*, displayed regularly recurring estuarine and littoral thermal features, was subject to SFP analysis.

No residual anomalies were found which could reasonably be interpreted as relating to oil pollution.

(B) Tests of HCMM Thermal IR Band as a Means of Detecting U.K.
Power Stations

Because of a negative result derived from the synoptic examination of the imagery, it was decided to assess the capability of the HCMM imagery to detect heat sources in fixed localities. The thermal effects of centres of population are well known and were clearly in evidence in the HCMM IR imagery. It was desirable, however, to choose probable heat centres of small areal extent, in the tests, in order to move closer to the case of a small oil slick. Accordingly, it was decided to inspect the appropriate imagery for thermal waste from power stations.

Using data supplied by the Central Electricity Generating Board and by the South Scotland Electricity Board, 23 power stations with a generating capacity of ≥ 1000 MW and five power stations with a capacity of ≥ 2000 MW were located on 1:50000 Ordnance Survey Maps (1st and 2nd Series). The computer filing system was used to recall all imagery covering the 28 areas in question. Finally, every image which was both cloud free and of good quality in the region immediately around each map position was viewed in false colour and scanned sequentially, using the videodensitometer, so as to cover every patch under investigation.

The results showed that:

The station with the highest generating capacity (2400 MW), Long Annet (Firth of Forth) was undetectable. Evidently this station was not delivering any detectable thermal pollution in late May and early June 1978. Likewise, Cockenzie was undetectable on the same dates.

Kingsworth and Tilbury stations were both detectable; whereas West Thurrock proved to be indistinguishable from the urban background.

Hinkley Point and Aberthaw stations, both on the SW coast and removed from conurbations, were both detectable. A videodensitometric profile across Hinkley Point power station is reproduced in Fig. 23. Fawley and Pembroke were indistinguishable

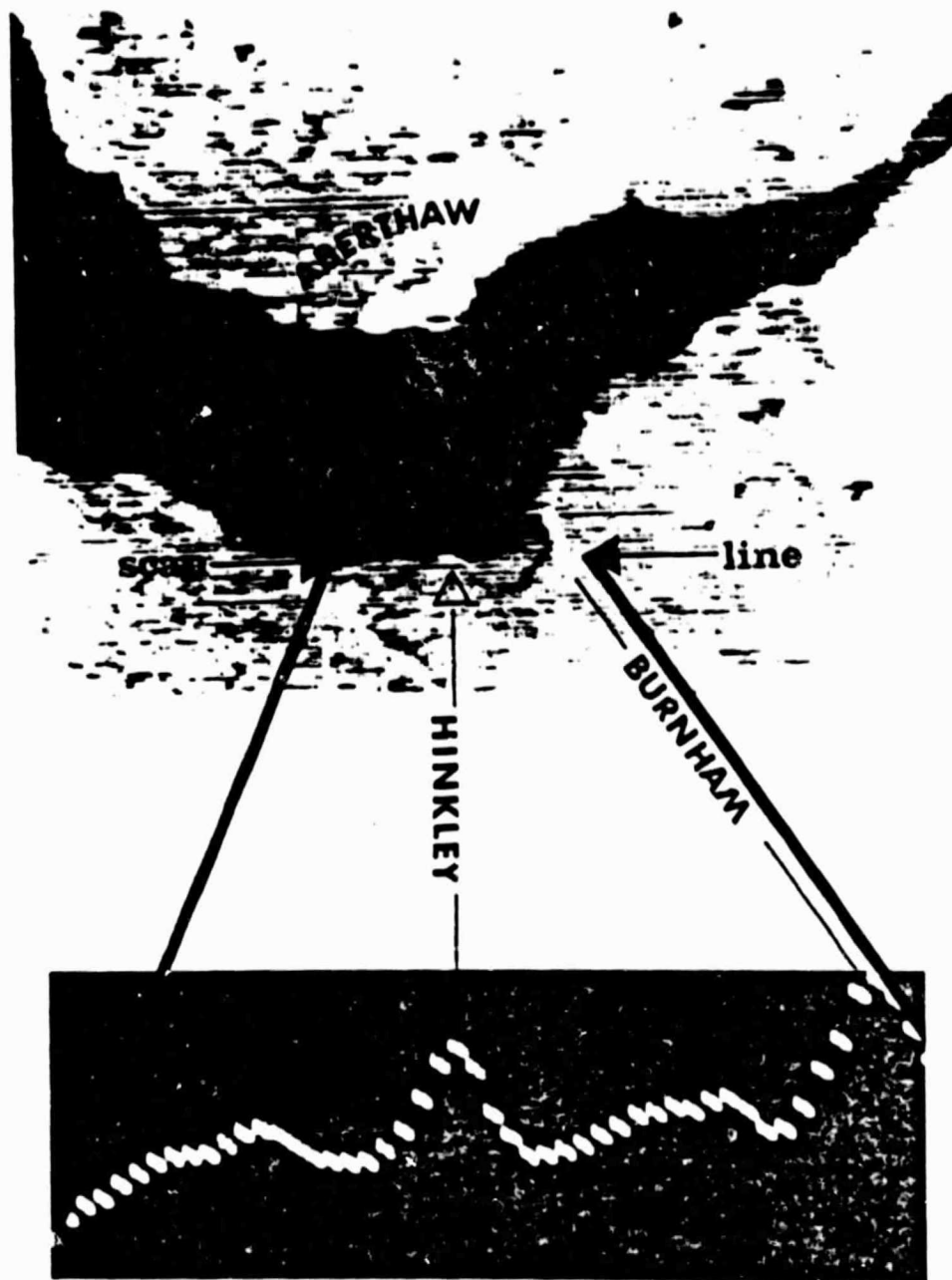


Fig. 23 Videodensitometric Profile across the centre of the thermal anomaly (open arrow head) generated by losses from the Hinkley Point Power Station, England. Losses from a second power station may be detected in the open, square box. (ECMM image DIR/344, of 1978, Jun. 11; A-AG046-13340-2).

from their principally industrial surroundings. Didcot, which is inland, was located with difficulty. A similar situation - and result - pertained in the case of Midlands power stations.

Although on the coast, Inverkip (Firth of Clyde) was undetectable.

In conclusion, some of the stations showed clearly discernible thermal losses; others, surrounded by a variety of thermal backgrounds, provided inconclusive evidence of thermal losses; while yet others were certainly invisible in the thermal IR channel of HCMM. Those stations in the latter category included Long Annet, which offered the highest potential energy output. The efficiency ratings will differ between power stations. In addition, at a given time of HCMM overpass, any station may be working at less than maximum power output. The range of results obtained was thought to be readily explicable in terms of these variables.

(C) Search for Reported Oil Slicks

A speically compiled card index of all oil spills reported in the calendar years 1978 and 1979 (see page 64) was used to sort those 79 category A spills, reported as being of one mile or more in length, from the remaining 52 category B spills, each of which was less than one mile in length.

For each category A event the computer filing system was used to recall all imagery corresponding to the date of spill. In case the spill was reported late, imagery corresponding to the day before the sighting was also extracted from the data bank; and the imagery for at least the two days following the date of report of spill was brought out for examination in case the first changes were "clouded out" and the spill persisted beyond that time. All these images were inspected visually for relevant coverage and for apparent freedom, or comparative freedom, from cloud in the area in question. Eight images (Table 5) survived these restrictions and each was scrutinised for any anomaly which could have been the result of an oil spill. Since the reported locations of the spills were poorly defined (the only description offered being that given in Table 5) scaling from maps was sufficient to pinpoint the centre of an area of somewhat arbitrary size that was then examined in false colour. Six of the areas were in fact covered by patchy cloud. The remaining two areas, identified in Table 5, are depicted in Figs. 24 and 25.

Even high-resolution videodensitometric scans failed to show any anomaly in any of these areas. The Peterhead report related to a spill that might have been little more than a mile in length; and the spill might have suffered dispersal a day or so later, when the area was recorded by HCMM. Probably, the Lizard Point report also related to a short spill; and the area in question was viewed some four days after the event. The area of the reportedly long spill "to the south of Plymouth" was viewed approximately three days after the event.

With these negative results, we proceeded to examine category B events in precisely the same manner. However, after rejecting images which were not free from cloud in the area in question, in each of the 52 cases, no images remained for further examination.

Table 5: Imagery Used in Search for Reported
Oil Spill Events

<u>HCMM Image and Date</u>	<u>Event Location, Length, and Date</u>
A-A0050-13120-2, DIR/145, 15/06/78	50 miles NE Peterhead, > 1 mile, 14/06/78
*A-A0116-13330-2, DIR/029, 20/08/78	28 miles E Lizard Point, > 1 mile, 16/08/78
A-A0168-13060-2, DIR/010, 11/10/78	Amlwch, > 1 mile, 10/10/78
A-A0174-13170-2, DIR/192, 17/10/78	Amlwch, v. <i>supra</i>
A-A0169-13240-2, DIR/189, 12/10/78	St. Brides Bay, > 1 mile, 12/10/78
A-A0180-02270-2, NIR/076, 23/10/78	12 miles NW Scilly, > 1 mile, 19/10/78
A-A0287-13200-2, DIR/170, 07/02/79	2 mile x 200 yards, 1½ mile NE Belfast
A-A0287-02190-3, NIR/020, 07/02/79	Lough, 07/02/79
*A-A0356-13030-2, DIR/430, 17/04/79	S of Plymouth, several miles, 14/04/79

* Apparently completely free of cloud in relevant area.



Fig. 24 Lizard Point Spill Location (HCMM image DIF/G29,
of 1978, Aug. 20; A-AO116-13330-2).

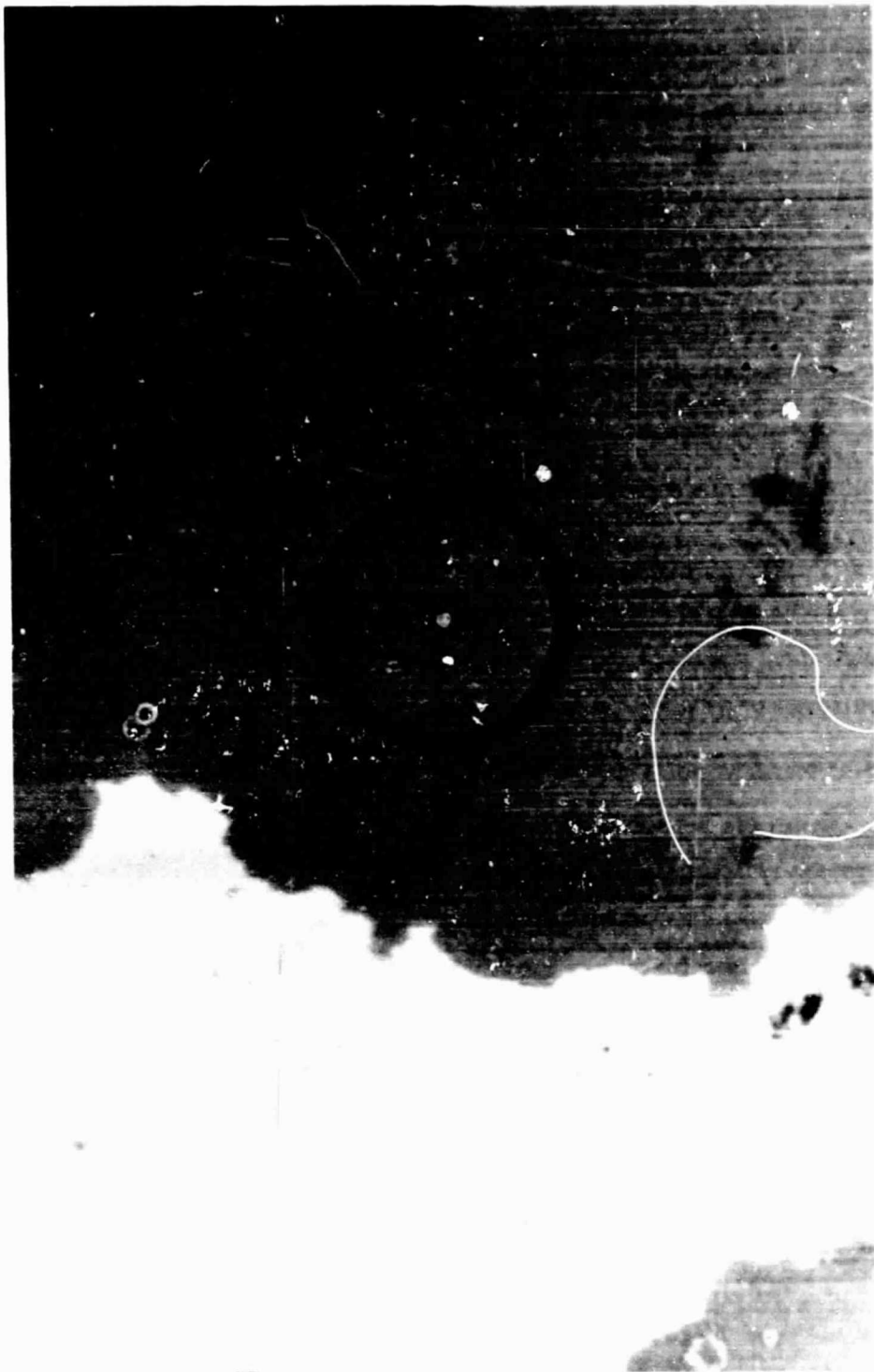


Fig. 25 Plymouth Spill Location (HCMM image DIR/430, of 1979, Apr. 17; A-AO356-13170-2).

A full report on the Amlwch (Table 5) spill reached us through the offices of the Marine Science Laboratories, Anglesey. At 3 p.m. on 10th October 1978 the forecastle lookout on the Shell Tanker "Litopa" observed a spray of oil discharging from a hose at Amlwch Marine Terminal, Anglesey. The discharge was arrested but the slick, which was then moving eastwards under the influence of the flood tide, extended some 1 km from east to west and some 200 m from north to south.

Estimates of the amount of oil spilled varied from 20 tons to 200 tons. The position and configuration of the slick changed over the following twelve days until there were no visible traces of it remaining in the area.

The extra detail contained in this report encouraged us to search for later, clear imagery of Amlwch, the HCMM imagery of 11th October (Table 5) having been rejected because of cloud. An attempt was made to correlate the image patterns of the appropriate marine areas in HCMM and NOAA 5 scenes with the report of the slick. The linear resolution (about 1 km) and signal/noise ratios of the NOAA 5 image - a positive print representing the scene on 1978, October 17 - were deemed insufficient for a detailed, intensive study of the area.

In order to improve discrimination between adjacent image areas our only suitable HCMM transparency - which also showed a 1978, October 17 scene - was, first, suitably masked. Pixels were identified readily in the enlarged print of Anglesey (Fig. 26) taken from that transparency. The masked portion of the transparency (DIR) was mounted on the microscope stage and that part of the image which lay within the white rectangle (arrowed, in Fig. 26) was examined using the CCTV camera in position above the x10 eyepiece. With an objective magnifying x4, the enlargement was more than sufficient to resolve the individual pixels.

The false colour rendering of the smaller area in which the slick was reported was digitised and corrected for shading and illumination errors (Fig. 27a).

Clearly, a region cooler than its surrounding sea area is observed about 2 km NW of Puffin Island (Fig. 27a and b). The observed effect is attributable to a temperature difference



Fig. 26 Anglesey Spill Location (ICMM image DIR/192, of 1978, Oct. 17; A-M0174-13170-2).

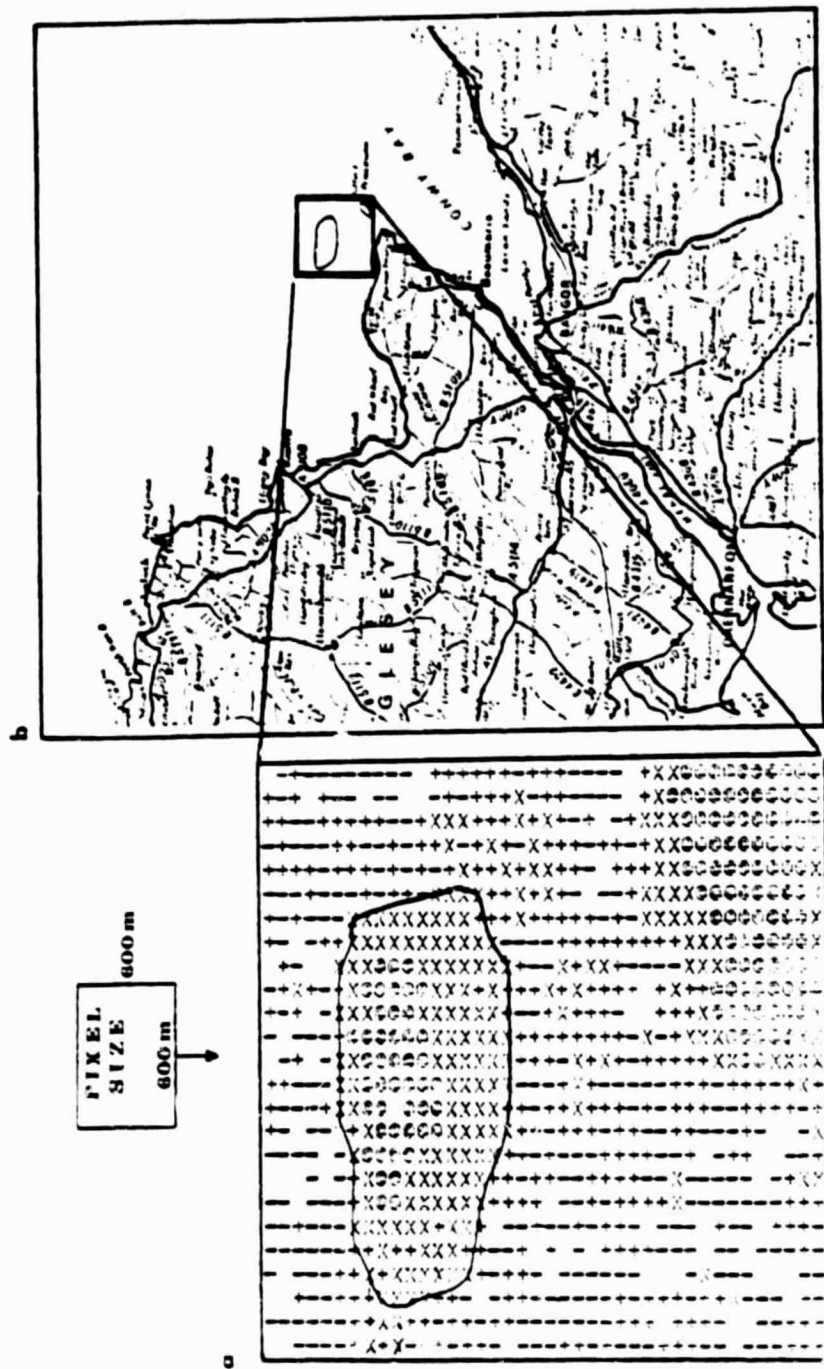


Fig. 27 a. Digital rendering of IR grey levels in area around Anglesey Slick
 b. Definition of area represented in a.

estimated to be about 1 K. The spatial extent of the cool patch is estimated, from Fig. 27a, and from the corresponding false colour image, to be at least 2 km in the E-W direction and 1 km from N to S. The presence of some cloud (Fig. 26) - and some reported fog - in the area does not, however, lead one to an unambiguous interpretation in this case. Indeed, even the extent of the cloud which partially covers Puffin Island is difficult to assess because of the inherent limits of spatial resolution provided by the imagery.

SIGNIFICANT RESULTS DRAWN FROM PROJECT

(A) Comment on the Video Processor

The image processing techniques developed at Lancaster are well adapted to the rapid exploration of large areas, and to the isolation and study of local areas, which exhibit small temperature differences between themselves and their surroundings.

(B) Results drawn from the Simulators

The thermal behaviour of a layer of North Sea oil covering water has been compared with that of a similar volume of uncontaminated water held under identical environmental conditions using outdoor and indoor simulators, including a wind tunnel. These experiments showed that, for oil layer thickness in excess of between 1 mm or 2 mm and 2 cm, there was little dependence of oil surface temperature on the thickness of the oil layer; and that the surface temperature of the oil was consistently higher than that of the water surface. Under windless conditions and ambient temperature of about 10°C, the oil in the outside simulator achieved a temperature of 0.2 to 0.5 K higher than the water surface. As the ambient temperature climbed past 20°C, the oil (in the indoor simulator) assumed a 1.0 K positive temperature increment relative to the water at low values of the relative humidity, and that temperature difference decreased towards zero as the relative humidity was increased towards 100%.

Computer simulation showed that the temperature of a layer of oil on water closely followed the temperature of the ambient air under conditions of turbulent air flow. In the field the air flow might be expected to become turbulent at wind speeds of $\sim 4 \text{ m s}^{-1}$. The results of our wind tunnel experiments were consistent with these predictions. As the air speed increased from zero, the temperature differential between the oil layer and the water surface also increased, for a given air temperature and humidity.

Under "still air" conditions, the water only system clearly cooled by evaporation more than the system with the oil layer. As the humidity increased, the rate of evaporative cooling decreased. As the wind speed increased, more energy was transferred from the air motion to the fluid systems and there was more frictional dissipation of energy in the oil-layer than in the surface layer of water in the "water only" system.

Thus unbroken oil slicks thicker than 1 or 2 mm would, at sea, appear slightly warmer than the surrounding water even if the oil were spilled at the same temperature as that of the water.

The relationship between the temperature differential of such an oil spill and the surrounding sea, on the one hand, and the wind velocity, on the other hand, would not be linear. Increasing the surface wind velocity into the non-laminar flow regime would lead to break-up of the slick and, in practice, the resulting temperatures would be difficult to predict. At the edges of a spill, or in the case of a spill that, with time, had largely dispersed laterally, the oil might spread to become a film of thickness less than our experimental minimum of 1 mm. It is possible that the cool area we discovered some seven days after the Anglesey spill represented one such case. Oil spills with warm central regions and cool edges, relative to their marine surroundings, were illustrated by Parker and Cormack (Ref. 1). It is also evident that the emulsification processes described by the same authors would lead to the necessity, in practice, to modify the ideal boundary results relating to temperature regimes in the experiments described here.

(C) Comments on Sea Truth

On a synoptic scale, the principle source of sea truth lay in the Department METO 12c of the Meteorological Office at Bracknell, England. The number of sea surface points at which data have been measured within the bounds of an area recorded in an HCMM image is small. The number reduces even further when parameters such as wind vector are required as well as temperature. On the other hand, when tight control of measured sea surface temperatures was available, the data were found to pertain to too small an area too close to the coast to be of any use in the calibration of HCMM images.

Oceanic thermal fronts tend to be rather stable features of the seas around the U.K. Hence, in producing a synoptic temperature map, it is realistic to assemble temperatures measured at different points over a time interval of several days and use them to construct maps of isotherms. Even with an integration time of five days, local isotherms (as opposed to synoptic ones) are not necessarily reliable. With clear skies, calibrated HCMM thermal IR imagery would greatly improve our capability of producing isothermal charts of sea surfaces on a given date and at a given time. On a completely clear day or night the HCMM thermal channel provides a much better picture of the distribution of sea surface thermal anomalies than that provided by all the *in situ* measurements in the seas around the U.K.

(D) Comments on HCMM Images

The best HCMM imagery from NASA virtually attained the predicted resolution. Drop-outs (principally pixels, rarely whole lines) were minimal, particularly in the more recent data. By comparison, drop-outs appeared to be more numerous on the hard copy, QL imagery received from Lannion.

Raster lines proved troublesome on several occasions. The raster lines, which are present in the original transparencies, can be an important limiting factor in the image interpretation. Spurious herring-bone patterns commonly appeared in the IR imagery. These patterns, found on many occasions, were found to have a wavelength of the order of a few pixels and were generally accompanied by a grainy texture in addition to the spurious intensity modulations of the raster lines. This last mentioned defect was a consistent feature of the IR imagery.

The temperature resolution of the HCMM system, as investigated using our video processor, appeared to be adequate. Calibration using sea truth or ground truth proved impossible because of either insufficient spacial resolution or scarcity of reliable sea surface temperatures.

(A) Characteristics of Oil Spills in the Thermal Infra-red

There was no major oil spill or slick in the seas around the U.K. in the calendar years 1978/1979; nor was there one in the year 1980 up to the time of the present report. All except possibly one of the longer minor spills reported to us were invisible to HCMM because of cloud, and the shorter spills reported were undetectable because of image noise or lack of sufficient resolving power of the detectors carried by the Explorer-A satellite.

A discharge of crude oil to the north of Anglesey on 10th October 1978 was reported to be changing its form, appearance and location over the next twelve days. Generally speaking, the area covered by the oil increased following the date of spillage, even though the spraying of dispersant commenced on the date of spill. On 11th and 12th October two separate slicks were reported (sizes "3 miles x 2 miles" and "1½ miles x 1 mile" on 11th October) but were not seen on HCMM images 11/10/78 DIR frame 010, A-A0168-13060-2 and 12/10/78 DIR frame 189 (A-A0169-13240-2), which were apparently cloud free in the area, possibly because of strong raster lines, and possibly because the oil had responded well to the dispersant and was breaking up, leaving a clear sheen between oil patches. Nevertheless, a report for 17th October, 1970, described a colourless sheen, partly covered with brown mousse, measuring "4 to 5 miles" x "½ mile" in area; and it was on a HCMM image taken on 17th October (DIR frame 192, A-A0174-13170-2) that we measured an anomalous cool patch measuring at least 2 km x 1 km (see page 60). The sea had been rough prior to this observation, and some fog had been reported, but the position and area of the patch corresponded closely to those in the report of the development of the spill. We now conclude that the HCMM image of 17th October possibly did reveal the presence of oil.

Now the experimental work with simulators showed clearly that crude oil spills thicker than 1 or 2 mm were measurably warmer than the surrounding water, under still air conditions,

and even warmer than that under windy conditions (with surface air speed up to at least 8 m s^{-1}). It was reasoned that these circumstances arose because of the preferred evaporative cooling of the water surface and because of the preferred transfer of kinetic energy from the overflowing air to the oil surface by the mechanism of viscous dissipation of energy. Uniform films of oil much thinner than 1 mm were difficult to sustain outside, in a windy situation, and, in the laboratory work, the finite size of the PRT sensors dictated a minimal thickness, of the layer to be measured, of 1 to 2 mm. However, it is clear that, for thin films of oil, or for areas of patchy oil, the effects of both of the aforementioned mechanisms would be reduced in magnitude: the evaporative losses in the oily film, or oil-water emulsion layer, or brown mousse and water area) would be greater, generally, than in the case of a uniformly thick layer of oil; and the mean amount of thermal energy generated in a "thin" slick by means of the viscous dissipation mechanism - and in a system of mousse rafts which, judging from our experiments, would tend to behave rather rigidly and simply to move by translation and bob up and down in the water rather than to shear internally - would be less than in the case of a fresh, thick spill of oil.

Estimates of the amount of oil discharged in the Anglesey event spanned the range 20 to 100 tons. Spread over an area equivalent to a few resolution elements of HCM image this would provide an oil layer of equivalent thickness $< (0.1 \text{ mm to } .01 \text{ mm})$. An oil layer of this thickness would certainly be closer to assuming the temperature of the underlying water than would the oil forming the thicker layers examined in our experiments.

Airborne, thermal IR images (Ref. 2) of the major Ekofisk slick (April, 1977) showed that the thinner, bounding regions of a slick may appear cooler than the sea bounding the slick, whereas the thicker, central regions may appear the warmer. In this case, the spilt oil had, initially, a high intrinsic temperature ($\sim 80 \text{ C}$), and the apparently cooler peripheral areas

of the spill were reported to be of an oil-water emulsion $\sim 10 \mu\text{m}$ thick only. The peripheral areas of the spill appeared cooler than the uncontaminated sea because the emissivity of the oil was less than that of the water. However, the wind speed was $\sim 10 \text{ m s}^{-1}$ and this would have made a contribution to the observed temperature differences. Thermal and side-radar airborne measurements of controlled spills of crude oil in the North Sea were reported by Parker and Cormack (Ref. 1). The warmer centre and cooler edges, relative to the surrounding sea water, appeared to persist in this imagery even though the oil which was spilled was not reported to be at a high temperature. Indeed, the authors explained the effect in terms of solar heating: the oil had a lower thermal conductivity than the water, so the surfaces of the thicker layers of oil became warmer than either the water, or the thinner oil/water emulsion, surfaces. Once again, our work indicates that wind speed, reported by Parker and Cormack as 6 to 8 m s^{-1} in one controlled test and 3 to 5 m s^{-1} in another, is a factor to observe when considering the thermal regime of an oil slick. Parker and Cormack's adoption of a thickness of 1 mm of oil beneath surfaces registering a higher temperature than that of the sea, and a thickness of 0.1 mm of oil beneath surfaces apparently colder than the sea is consistent with our observations and computations; but we showed that a temperature difference of $\sim 2 \text{ K}$ between a "thick" oil surface and a water surface in the same environment could be attained in the absence of solar radiation.

(B) Detection and Monitoring of Oil Spills

It is clear from the foregoing analysis that an oil spill at sea may appear warmer (if the oil is thick) or cooler (if the oil is thin) than the surrounding water. A fairly fresh spill will be thick in the central parts and thin in the peripheral parts. The emulsification process will start as soon as the oil makes contact with the water and the surface properties of a film of oil spilled on water will change accordingly. Because of the motion of the water, a thin film of oil soon breaks into rafts and disperses with the emulsification process in operation. A thick layer of oil takes a longer time to mat and form mousse. In our experiments, mousse left in an outdoor tank for two months became fairly rigid and resisted internal shearing and flexing as a result of wind and water motion. With the sun shining on the experiment, the surface of the old mousse became warmer than the water. Hence the apparent temperature of an old slick (which has not been dispersed by the action of heavy seas) in which mousse features prominently would be dependent on the ratio of the integral area of mousse rafts to the total area of inter-raft water; and the temperature, read as a mean, would probably be above the temperature of the surrounding water under daytime conditions and below the temperature of the surrounding water at night. In this case, the effect of thermal dissipation in the oil by wind energy would be ineffective in raising the temperature of each mousse raft.

Because of these thermal characteristics of oil spills, it would seem to be possible, in principle, to distinguish them, in the thermal IR, from other pollutants. In practice, this method would require monitoring of a sea area at daily intervals rather than detection on one occasion alone.

Any single thermal IR image may show an anomaly as a result of an oil spill, fog, cloud, shallow sediments, pollutants other than oil, localised sea surface changes because of the presence, below, of fish, and so on. Pollutant dumping grounds and the location of shallow sediments are perhaps well known. Fog tends to recur in littoral strips and patches and would appear to be cool. Isolated patches of thin cloud were, we

found, the most troublesome features in our search for oil patches. However, because they occur at positive altitudes relative to the sea surface features, clouds could be identified and separated from oil patches, in principle, using stereos-imagery.

However, surface winds commonly split an oil spill into several parts and draw out each part into an elongated feature with its major axis pointing sub-parallel to the wind direction. This itself is a diagnostic characteristic of an oil spill of sufficient volume. In our investigation of sea truth, we found surface wind vectors to be particularly unreliable for the purposes of composing a synoptic map of wind flow. The quoted directions sometimes changed abruptly between adjacent stations; and the velocities which were quoted sometimes varied non-systematically between stations. What may be needed for the construction of meaningful surface wind maps is a network of instrumented buoys; but, in the meantime, synoptic weather maps and oil slick morphology can be helpful in determining wind direction if not surface wind velocity.

Ideally, an oceanic network of buoys carrying instruments to monitor, at least, air and water temperature, surface wind velocity, waves and solar radiation flux received - all at a given co-ordinate fix and time - might be established over an area large enough to be many times the resolving capability of any future oil detection satellite. These buoys would transmit the sea truth to the satellite, or elsewhere, for correlation with the imagery of the same area acquired by the satellite. Coupled with either the monitoring of an (artificial) slick in the area or with more sophisticated and extensive analytical or experimental work than that described here on the thermal regime of oil slicks, such correlations might be used as a basis for the interpretation of marine data collected by a future satellite. The ARGOS system (Ref. 3) offers the potential of collecting and providing the sea truth.

During the present exercise, the limitations of the HCMM system have been clarified. The angular resolution offered by the HCMM system needs to be reduced by a factor of several units

if a satellite surveillance system in the thermal IR is to be used to search for spills of small quantities of oil. This might be achieved through the use of IR radiometers of greater aperture. Most of the spills we investigated were of the order of one pixel in size; and the problems associated with the evaluation of small sized events have been exemplified in the case of the Amlwch oil spill. In many cases, the existence of raster lines in the original images provided major imperfections which far outweighed those introduced by electronic shading and illumination effects in our video-processing equipment. Better contrast stretching, applied particularly to the positive IR transparencies showing marine areas would have been of assistance in our densitometric analyses and subsequent interpretations. Indeed, in our case, the HCM system was working on the edge of the expectancy threshold for pollutant detection. Thus a larger radiometer system producing images of improved quality might profitably be used for oil slick detection work. The provisos are that (a) one would require satellite overpass at a daily rate and (b) the marine area selected for viewing would be one, normally, largely free of cloud.

The synoptic search for oil slicks might be automated through the use of a flicker technique: map correct data from successive images of the same scene would be strobed to a computer programmed to compare the photometric brightness of corresponding image elements secured on successive days. A null method of flickering out regular parts of a scene might be employed so as to highlight the anomalies and pin their forms and locations. Clouds might be identified if, instead of preparing one image, the satellite transmitted a stereo pair of images, per pass.

However, in many areas of the world there is commonly a high proportion of cloud cover (certainly this is so in the North European sea areas); and such an imaging system would best be accompanied by a large, microwave radiometer system. The desired results might be achieved only when facilities are available to place much larger microwave radiometric installations in orbit than are in use currently. In this way, detection and full monitoring of oil

slicks in chosen areas would become a realistic possibility and would dispense with the need for aircraft surveillance. The same, multisatellite system could be used also, for example, to study naturally occurring marine thermal features and to provide cloud and sea surface reports and forecasts for ships. All these measurements might well be correlated with radar observations of the sea surface.

(C) Computer Compatible Tapes

The first set of tapes delivered to us had not been prepared in the physical format which we had requested (they were written at 800 bits per inch instead of 1600 bits per inch). We sent one of the tapes to Manchester to be read on a more flexible deck; but the tape was found to be unreadable due to parity failures.

The replacement CCT's - ordered on 25th June, 1980 - are encoded in a mixture of ASCII, binary and octal code systems, all using 8 bit words. At Lancaster we have ready access to an ICL mainframe computer which, like all ICL machines, uses 6 bit words. Thus, to read a non-ICL tape it is essential to re-block the information as it is read from the tape; and a conversion table must be supplied. Our User Services Department has standard system macros to read tapes in all "foreign" codes (ASCII, BCD, EBCDIC, etc.), but only if the entire tape is in the same code. Thus we are forced to read the tape several times, each read cycle retrieving part of the tape contents. We then have to merge the correctly translated parts of the files, created by the reading runs, into a single, valid file. Since there is not an exact word-to-word correspondence between the original tape and the files produced by reading, this operation is, in itself, non-trivial. To date, Dr. Wilson has been able to read the ASCII parts of the tapes perfectly but has not yet read the pure binary sections: these are the most important sections since they contain the numerical data in the frames.

It would be of great value if, in future, data products of this sort were supplied in a single encoding system, to minimise the translation problems.

ACKNOWLEDGEMENTS

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We thank Norpipe Petroleum Limited (U.K.), Middlesbrough, for very kindly supplying and delivering two gallons of crude oil at no cost to us. Information on the Anglesey spill reached us through the offices of the Marine Science Laboratories, Anglesey.

- 1 Parker, H.D. and Cormack, D., "Evaluation of Infrared Line Scan (IRLS) and Side-Looking Airborne Radar (SLAR) over Controlled, Oil Spills in the North Sea", Warren Spring Laboratory of the Department of Industry, Report No. LR 315(OP), April, 1979.
- 2 Groupement pour le développement de la télédétection aérospatiale, "Ekofisk Operation", GDTA, France, 28 April, 1977.
- 3 "The Argos Satellite-based Data Collection and Platform Location System"; and "Argos Users Guide" March 1978. Service Argos, Centre National d'Etudes Spatiales, Toulouse.

HCTM - Map Plotting Programmes.

This note describes in some detail the six subroutines associated with the display of digitised geographical data. It does not describe the method of deriving geographical data from an examination of HCTM images, a procedure which will be discussed in a future note.

Of the six subroutines one ($\emptyset$ TLN) is an essential preliminary to the use of the three other plotter control routines (DRSCN, C $\emptyset$ AST and GRDTH). The remaining two routines are called by the above four for the computation of various parameters. MERC is required by all four; EDGPT only by DRSCN and C $\emptyset$ AST. Following a call to $\emptyset$ TLN, calls to DRSCN, C $\emptyset$ AST and GRDTH may be made in any order.

DRSCN, C $\emptyset$ AST and GRDTH all read data, which govern pen movements, referred to by means of card numbers. These numbers form part of the labels at the extreme right of every line. Card input data are desirable since the input to DRSCN and GRDTH will vary from plot to plot. However, the subroutine C $\emptyset$ AST plots a stylised coastline by reference to a standard data bank. It is assumed that a list of geographical coordinates representing successive points along the coastlines of interest will be stored in a computer file; and that the file will be ATTACHed at compilation time and accessed by an appropriate change in the READ instruction in C $\emptyset$ AST.

Individual subroutines are described below. Positions within each subroutine are referred to by means of card numbers.

Subroutine #TLN

This subroutine is an essential preliminary to the use of any of the other mapping subroutines. It calls standard plotting subroutines and MERC (q.v.). A map outline is drawn in all cases; a latitude/longitude grid is drawn only in response to a specific request for such.

The operation of the subroutine is (c.f.listing):

Cards 1 to 258. Entry and notes; definition of variables; ~~COMMON~~ definition of useful variables.

Cards 260 and 270. Initialisation of essential variables used subsequently by other plotting subroutines.

Cards 280 to 320. Drawing of map outline.

Card 330. Positioning of plotter pen at the geometrical map centre and definition of this point as the origin for subsequent plotter operations.

Card 340. Decision point governing generation, or otherwise, of a latitude/longitude grid.

Cards 350 to 356. RETURN and comment cards.

Cards 360 to 400. Defines the cartesian coordinates, relative to zero latitude and longitude, of the geographical point which is placed at the geometrical map centre. These coordinates are later used to adjust other cartesian coordinates expressed relative to zero latitude and longitude to a system having origin in the map centre.

Cards 410 to 480 and 520. Computation of x coordinates of successive parallels of longitude. Cards 460 and 470 ensure that only parallels lying within the map boundaries are considered.

Cards 490 and 500. Drawing of computed parallel across the extent of the map.

Card 510. Labelling of parallel of longitude just drawn with its degree value to one decimal place.

Cards 530 to 600 and 640. Computation of y coordinates of successive parallels of latitude. Cards 590 and 600 ensure that only parallels lying within the map boundaries are considered.

Cards 610 and 620. Drawing of computed parallel across the extent of the map.

Card 630. Labelling of parallel of latitude just drawn with its degree value to one decimal place.

Note. In order to prevent a plotter error being flagged it is best if argument YLEN be ≤ 70.0 . YLEN may take any value, though it must be ensured that clearance for the use of the necessary paper has been obtained by an appropriate call to PAPER in the main programme.

 LISTING OF 'XC08.STOREF(1/)' PRODUCED ON 20JUN77 AT 16.33.34
 OUTPUT BY LISTFILE IN 'XC08.MOP' ON 30JUN77 AT 11.51.14 USING 193
 DOCUMENT STOREF

A1	SUBROUTINE OTLN(CLAT,CLON,XLEN,YLEN,ALAM,BET,SCALE,DIV,HALFX,	OTLN	1
A2	1 HALFY,JJ)	OTLN	2
A3 C		OTLN	10
A4 C	THIS ROUTINE DRAWS A RECTANGULAR MAP OUTLINE AND, OPTIONALLY, INSERTS	OTLN	20
A5 C	A MERCATOR LATITUDE/LONGITUDE GRID AT SPECIFIED INTERVALS. IT IS AN	OTLN	21
A6 C	ESSENTIAL PRELIMINARY TO THE USE OF SUBROUTINES 'DRSCH', 'COAST', OR	OTLN	22
A7 C	'GRTH'	OTLN	23
A8 C		OTLN	30
A9 C	VARIABLES AND ARGUMENTS ---	OTLN	40
A10 C	CLAT,CLON - LATITUDE AND LONGITUDE OF GEOMETRICAL MAP CENTRE	OTLN	50
A11 C	(DEGREES).	OTLN	51
A12 C	CLATN,CLONR - RADIAN EQUIVALENTS OF CLAT AND CLON	OTLN	60
A13 C	CONF - CONVERSION FACTOR DEGREES TO RADIAN	OTLN	65
A14 C	XLEN,YLEN - LENGTH AND HEIGHT OF MAP	OTLN	70
A15 C	ALAM,BET - LATITUDE AND LONGITUDE (DEGREES) OF GRID ORIGIN.	OTLN	80
A16 C	GRID LINES ARE PLOTTED ONLY FOR VALUES GE THESE.	OTLN	81
A17 C	SCALE - MAP SCALE	OTLN	90
A18 C	DIV - INTERVAL BETWEEN GRID LINES (DEGREES).	OTLN	100
A19 C	HALFX - HALF MAP WIDTH	OTLN	110
A20 C	HALFY - HALF MAP HEIGHT	OTLN	120
A21 C	JJ - FLAG VARIABLE GOVERNING DRAWING OF GRID -- JJ.LE.0 NO	OTLN	130
A22 C	GRID, JJ.GE.1 CAUSES GRID.	OTLN	131
A23 C	CPOSX,CPOSY - CARTESIAN MAP COORDINATES OF (CLAT,CLON)	OTLN	140
A24 C	EXPRESSED RELATIVE TO ZERO LATITUDE AND LONGITUDE	OTLN	141
A25 C	XOUT,YOUT - TEMPORARY VARIABLES OUTPUT BY 'MERC'.	OTLN	150
A26 C	DIFLON - LONGITUDE INTERVAL (DEGREES) CORRESPONDING TO HALFX	OTLN	160
A27 C	BETL - LONGITUDE OF WEST MAP EDGE (DEGREES)	OTLN	170
A28 C	BETR - LONGITUDE OF EAST MAP EDGE (DEGREES)	OTLN	180
A29 C	BET - LONGITUDE OF CANDIDATE GRID LINE TO BE INSERTED	OTLN	190
A30 C	TEMP - X-COORDINATE OF PARALLEL OF LONGITUDE TO BE INSERTED	OTLN	200
A31 C	LATER Y-COORDINATE OF PARALLEL OF LATITUDE TO BE	OTLN	201
A32 C	INSERTED	OTLN	202
A33 C	TEMP1 - VARIABLE ENABLING SEPARATION OF LABEL FROM MAP EDGE	OTLN	210
A34 C	ALAMR - RADIAN EQUIVALENT OF ALAM	OTLN	220
A35 C		OTLN	230
A36 C		OTLN	240
A37 C		OTLN	240
A38 C		OTLN	255
A39 C		OTLN	256
A40 C	*** THIS INITIAL SECTION DRAWS THE MAP OUTLINE ***	OTLN	257
A41 C		OTLN	258
A42	HALFX = XLEN/2.0	OTLN	260
A43	HALFY = YLEN/2.0	OTLN	270
A44	CALL PLOT(2.0,2.0,-3)	OTLN	280
A45	CALL PLOT(XLEN,0.0,2)	OTLN	290
A46	CALL PLOT(XLEN,YLEN,2)	OTLN	300
A47	CALL PLOT(0.0,YLEN,2)	OTLN	310
A48	CALL PLOT(0.0,0.0,2)	OTLN	320
A49	CALL PLOT(HALFX,HALFY,-3)	OTLN	330
A50	IF(JJ.GE.1) GO TO 2	OTLN	340
A51	1 RETURN	OTLN	350
A52 C		OTLN	353
A53 C	*** THE REMAINDER OF THE SUBROUTINE GOVERNS THE DRAWING OF THE	OTLN	354
A54 C	LATITUDE/LONGITUDE GRID ***	OTLN	355
A55 C		OTLN	356
A56	2 CLATN = CLAT*CONF	OTLN	360

117		CLOMR = CLON*CONF	OTLN 370
118		CALL MERC(CLATR,CLOMR,XOUT,YOUT)	OTLN 380
119		CPOSX = XOUT*SCALE	OTLN 390
120		CPOSY = YOUT*SCALE	OTLN 400
121		DIFLOM = (HALFX/SCALE)/CONF	OTLN 410
122		BETL = CLON - DIFLOM	OTLN 420
123		BETR = CLON + DIFLOM	OTLN 430
124		BET = BET - DIV	OTLN 440
125	3	BET = BET + DIV	OTLN 450
126		IF(BET.LT,BETL) GO TO 3	OTLN 460
127		IF(BET.GT,BETR) GO TO 4	OTLN 470
128		TEMP = (BET - CLON)*CONF*SCALE	OTLN 480
129		CALL PLOT(TEMP,-HALFY,3)	OTLN 490
130		CALL PLOT(TEMP,HALFY,2)	OTLN 500
131		CALL NUMBER(TEMP,HALFY,0.35,BET,45.0,1)	OTLN 510
132		GO TO 3	OTLN 520
133	4	TEMP1 = HALFX + 0.1	OTLN 530
134		ALAM = ALAM - DIV	OTLN 540
135	5	ALAM = ALAM + DIV	OTLN 550
136		ALAMR = ALAM*CONF	OTLN 560
137		CALL MERC(ALAMR,0.0,XOUT,YOUT)	OTLN 570
138		TEMP = YOUT*SCALE - CPOSY	OTLN 580
139		IF(TEMP.LT,-HALFY) GO TO 5	OTLN 590
140		IF(TEMP.GT,HALFY) GO TO 6	OTLN 600
141		CALL PLOT(-HALFX,TEMP,3)	OTLN 610
142		CALL PLOT(HALFX,TEMP,2)	OTLN 620
143		CALL NUMBER(TEMP1,TEMP,0.35,ALAM,0.0,1)	OTLN 630
144		GO TO 5	OTLN 640
145	6	CALL PLOT(0.0,0.0,3)	OTLN 650
146		GO TO 1	OTLN 660
147		END	OTLN 670

↑*****

Subroutine DRSCN.

This subroutine locates the map positions of successive points along a digitised scan and joins these by straight lines. Should a scan be partially beyond the map boundary the subroutine uses EDGPT (q.v.) to determine the point at which the scan crosses the boundary and terminates the map drawing at that point.

N.B. Should two successive map positions lie beyond the map boundary, but in such a manner that if they were joined by a straight line a portion of that line would lie within the map boundary, the portion of line within the map boundary will not be drawn. Thus occasionally a segment of a scan will be omitted. This situation will in general occur near map corners and with coarsely digitised scans.

The operation of the subroutine is (c.f. listing):

Cards 1 to 90. Entry and notes, definition of variables; ~~COMMON~~ definition of useful variables.

Cards 100 and 110. Initialisation of A and B to zero.

Card 120. Set flag to indicate that, on entry, a scan is commencing.

Card 130. Read radian latitude and longitude of supplied point.

Card 140. Radian latitude cannot exceed $\pm \pi/2$. Values outside this range may be used as flags, therefore. $ALAT \geq 5.0$ is used to indicate that no more scans are to be drawn, and causes

immediate RETURN.

Card 150. $5.0 > ALAT \geq 4.0$ indicates that the current scan is completed, but that more are to follow. A loop back to card 120 resets the routine, therefore.

Cards 160 to 180. Compute map position corresponding to the supplied geographical position.

Cards 190 and 200. Determine whether the supplied point lies within or beyond the map boundary. If beyond, control passes to label 10 (card 210); if not, control passes to label 6 (card 280).

Cards 210 to 270. The point under consideration may be the first of a scan. If so $IF=2$ and control is passed from card 210 to label 4 (card 240); here IF is set to 1 to indicate that the point lies beyond the map boundary and A and B are initialised to the current values of $XOUT$ and $YOUT$; control then passes back to label 2 (card 130).

If the point under consideration is not the first of a scan IF records the status of the previous point considered. $IF=1$ indicates that the last point also lay beyond the map boundary, control passes directly to label 5 (card 250) therefore; the contents of A and B are replaced by $XOUT$ and $YOUT$; control again goes back to label 2 (card 130).

$IF=3$ indicates that the previous point lay within the map boundary and therefore a line must be drawn, control passes

to label 3 (card 220) where the position at which the scan crosses the edge is computed.

Card 230 draws a line from the current pen position (which will be at the map position of the previous point) to the point on the edge. IF, A and B are then adjusted and control passed back to label 2 (card 130).

Cards 280 to 350 and 375-377. A decision point similar to label 10, though at this point it is known that the current point lies within the map boundary.

IF=2 (point first of scan) transfers control to label 6 (card 370) where the pen is moved (pen up) to lie over the map position, IF is set to 3 for future use and control passes back to label 2 via label 5 as before and for the same reasons.

IF=3 (last point also within map boundary) moves the pen (down) from its current position to the position of the current map point and leaves it there; IF is set to 3 and control goes back to label 2 as before.

IF=1. (last point lay beyond map boundary) transfers control to label 7 (card 290) where the point at which the scan enters the boundary is computed; the pen is then transferred to this point (up) by card 300 and subsequently to the current map position (down) by card 310.

Control returns to label 2 as before.

Cards 360 and 370. Control arrives here by transfer from card 140 (q.v.) The pen is first returned (up) to the geometrical map centre, and control is then RETURNed to the calling program.

Cards 380 and 390. FORMAT and END.

#LISTING OF IXC08.STOREF(1/) PRODUCED ON 29JUN77 AT 14.33.35
#OUTPUT BY LISTFILE IN 'IXC08.MOP' ON 30JUN77 AT 14.51.30 USING 133
DOCUMENT STOREF

148	SUBROUTINE DRSCN(SCALE,HALFX,HALFY)		DRSN	1
149	C		DRSN	10
150	C	THIS ROUTINE PLOTS DIGITISED SCANS ON A PREPARED BASEMAP BY	DRSN	20
151	C	JOINING SUCCESSIVE MAP POSITIONS BY STRAIGHT LINES. THE MOVEMENT OF	DRSN	21
152	C	THE PEN IS SOLELY WITHIN THE MAP BOUNDARIES. THE ROUTINE ASSUMES	DRSN	22
153	C	THAT ON ENTRY THE PEN IS ZEROED ON THE GEOMETRICAL MAP CENTRE.	DRSN	23
154	C		DRSN	30
155	C	VARIABLES AND ARGUMENTS ---	DRSN	40
156	C	SCALE = MAP SCALE	DRSN	41
157	C	HALFX = HALF MAP WIDTH	DRSN	42
158	C	HALFY = HALF MAP HEIGHT	DRSN	43
159	C	A = STORAGE VARIABLE FOR X COORDINATE OF LAST POINT	DRSN	44
160	C	B = STORAGE VARIABLE FOR Y COORDINATE OF LAST POINT	DRSN	45
161	C	IF = FLAG FOR POSITION OF LAST POINT	DRSN	46
162	C	IF = 3 IMPLIES LAST POINT LAY WITHIN MAP BOUNDARY	DRSN	47
163	C	IF = 1 IMPLIES LAST POINT LAY OUTSIDE MAP BOUNDARY	DRSN	48
164	C	IF = 2 IMPLIES CURRENT POINT IS FIRST OF A SCAN	DRSN	49
165	C	ALAT,ALON = RADIAN LATITUDE AND LONGITUDE OF SUPPLIED POINT	DRSN	50
166	C	XOUT,YOUT = CARTESIAN MAP COORDINATES OF SUPPLIED POINT	DRSN	51
167	C	RELATIVE TO GEOMETRICAL MAP CENTRE	DRSN	51
168	C	XEDG,YEDG = CARTESIAN MAP COORDINATES OF A POINT ON THE	DRSN	52
169	C	INTERSECTION OF A STRAIGHT LINE JOINING SUCCESSIVE	DRSN	53
170	C	POINTS ON EITHER SIDE OF A MAP BOUNDARY WITH THAT	DRSN	54
171	C	BOUNDARY	DRSN	55
172	C	CENX,CENY = CARTESIAN MAP COORDINATES OF GEOMETRICAL MAP	DRSN	57
173	C	CENTRE RELATIVE TO ZERO LAT, ZERO LONG.	DRSN	58
174	C		DRSN	60
175	C	R.J.FRYER 3/3/77	DRSN	70
176	C		DRSN	80
177		COMMON PI,CONF,CENX,CENY	DRSN	90
178		A = 0.0	DRSN	100
179		B = 0.0	DRSN	110
180	1	IF = 2	DRSN	120
181	2	READ(3,100) ALAT,ALON	DRSN	130
182		IF(ALAT.GE.5.0) GO TO 9	DRSN	140
183		IF(ALAT.GE.4.0) GO TO 1	DRSN	150
184		CALL MFRC(ALAT,ALON,XOUT,YOUT)	DRSN	160
185		XOUT = XOUT*SCALE - CENX	DRSN	170
186		YOUT = YOUT*SCALE - CENY	DRSN	180
187		IF(ABS(XOUT).GT.HALFX) GO TO 10	DRSN	190
188		IF(ABS(YOUT).LE.HALFY) GO TO 6	DRSN	200
189	10	GO TO (5,4,3) IF	DRSN	210
190	3	CALL EDGPT(HALFX,HALFY,XOUT,YOUT,A,B,XEDG,YEDG)	DRSN	220
191		CALL PLOT(XEDG,YEDG,2)	DRSN	230
192	4	IF = 1	DRSN	240
193	5	A = XOUT	DRSN	250
194		B = YOUT	DRSN	260
195		GO TO 2	DRSN	270
196	6	GO TO (7,8,11) IF	DRSN	280
197	7	CALL EDGPT(HALFX,HALFY,XOUT,YOUT,A,B,XEDG,YEDG)	DRSN	290
198		CALL PLOT(XEDG,YEDG,2)	DRSN	300
199		CALL PLOT(XOUT,YOUT,2)	DRSN	310
200		IF = 3	DRSN	315
201		GO TO 5	DRSN	320
202	8	CALL PLOT(XOUT,YOUT,3)	DRSN	330
203		IF = 3	DRSN	340

204		GO TO 5	005N 350
205	0	CALL PLOT(0.0,0.0,3)	005N 360
206		RETURN	005N 370
207	11	CALL PLOT(XOUT,YOUT,2)	005N 375
208		IF = 3	005N 376
209		GO TO 5	005N 377
210	100	FORMAT(2F9.4)	005N 380
211		END	005N 390

↑*****

Subroutine CMAST

This subroutine is essentially identical to DRSCN (q.v.) Two modifications only have been made. Firstly the routine expects to receive the geographical coordinates of scan points expressed in degrees rather than radians. Cards 145 and 146 make the conversion degrees to radians to allow MERC to be used.

Secondly, a flag IFLAG is added to the argument list. IFLAG zero will cause the scan to be plotted as a broken line so that it can be distinguished from scans plotted by DRSCN. Appropriate branch points have been inserted to allow for this option and should be self explanatory.

N.B. The choice of a broken scan will greatly increase processing time. This option should therefore be used circum-
spectly.

BLISTING OF :KCOB.STORFF(1/) PRODUCED ON 29JUN77 AT 16.33.35

#OUTPUT BY LISTFIL IN 'KCOB.MOB' ON 30JUN77 AT 12.01.10 USING 133

DOCUMENT STORFF

212	SUBROUTINE COAST(SCALE,HALFX,HALFY,IFLAG)	COST	1
213 C		DRSN	10
214 C	THIS ROUTINE PLOTS DIGITISED SCANS ON A PREPARED BASEMAP BY	DRSN	20
215 C	JOINING SUCCESSIVE MAP POSITIONS BY STRAIGHT LINES. THE MOVEMENT OF	DRSN	21
216 C	THE PEN IS SOLELY WITHIN THE MAP BOUNDARIES. THE ROUTINE ASSUMES	DRSN	22
217 C	THAT ON ENTRY THE PEN IS ZEROED ON THE GEOMETRICAL MAP CENTRE.	DRSN	23
218 C		DRSN	30
219 C	THIS ROUTINE IS BASICALLY SIMILAR TO DRSN (R,V,) EXCEPT THAT IT	COST	31
220 C	EXPECTS SUPPLIED COORDINATES IN DEGREES, AND HAS AN OPTION TO PLOT	COST	32
221 C	SCANS AS BROKEN LINES.	COST	33
222 C		COST	35
223 C	VARIABLES AND ARGUMENTS ---	DRSN	40
224 C	SCALE = MAP SCALE	DRSN	41
225 C	HALFX = HALF MAP WIDTH	DRSN	42
226 C	HALFY = HALF MAP HEIGHT	DRSN	43
227 C	A = STORAGE VARIABLE FOR X COORDINATE OF LAST POINT	DRSN	44
228 C	B = STORAGE VARIABLE FOR Y COORDINATE OF LAST POINT	DRSN	45
229 C	IF = FLAG FOR POSITION OF LAST POINT	DRSN	46
230 C	IF = 3 IMPLIES LAST POINT LAY WITHIN MAP BOUNDARY	DRSN	47
231 C	IF = 1 IMPLIES LAST POINT LAY OUTSIDE MAP BOUNDARY	DRSN	48
232 C	IF = 2 IMPLIES CURRENT POINT IS FIRST OF A SCAN	DRSN	49
233 C	ALAT,ALON = DEGREE LATITUDE AND LONGITUDE OF SUPPLIED POINT	COST	50
234 C	XOUT,YOUT = CARTESIAN MAP COORDINATES OF SUPPLIED POINT	DRSN	51
235 C	RELATIVE TO GEOMETRICAL MAP CENTRE	DRSN	51
236 C	XEDG,YEDG = CARTESIAN MAP COORDINATES OF A POINT ON THE	DRSN	52
237 C	INTERSECTION OF A STRAIGHT LINE JOINING SUCCESSIVE	DRSN	53
238 C	POINTS ON EITHER SIDE OF A MAP BOUNDARY WITH THAT	DRSN	54
239 C	BOUNDARY	DRSN	55
240 C	CENX,CENY = CARTESIAN MAP COORDINATES OF GEOMETRICAL MAP	DRSN	57
241 C	CENTRE RELATIVE TO ZERO LAT, ZERO LONG.	DRSN	58
242 C	IFLAG = FLAG GOVERNING CHOICE OF SOLID OR BROKEN LINE	COST	60
243 C	IFLAG ZERO = SOLID LINE	COST	61
244 C	IFLAG = 1 = BROKEN LINE	COST	62
245 C	IFLAG1 = IFLAG PLUS ONE	COST	63
246 C		COST	69
247 C		COST	70
248 C		DRSN	80
249	COMMON B1,CONF,CENX,CENY	DRSN	90
250	IFLAG1 = IFLAG + 1	COST	95
251	A = 0.0	DRSN	100
252	B = 0.0	DRSN	110
253	1 IF = 2	DRSN	120
254	2 READ(3,100) ALAT,ALON	COST	130
255	IF(ALAT.GE.100.0) GO TO 9	COST	135
256	IF(ALAT.GE.90.0) GO TO 1	COST	140
257	ALAT = ALAT*CONF	COST	145
258	ALON = ALON*CONF	COST	146
259	CALL MERG(ALAT,ALON,XOUT,YOUT)	DRSN	160
260	XOUT = XOUT*SCALE - CENX	DRSN	170
261	YOUT = YOUT*SCALE - CENY	DRSN	180
262	IF(ABS(XOUT).GT.HALFX) GO TO 10	DRSN	190
263	IF(ABS(YOUT).LE.HALFY) GO TO 6	DRSN	200
264	10 GO TO (5,4,3) IF	DRSN	210
265	3 CALL EDAPT(HALFX,HALFY,XOUT,YOUT,A,B,XEDG,YEDG)	DRSN	220
266	GO TO (15,14) IFLAG1	COST	225
267	15 CALL PLOT(XEDG,YEDG,2)	COST	230

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268		GO TO 4	COST 233
269	16	CALL BROKEN(XEDG,YEDG,1)	COST 236
270	4	IF = 1	DRSN 240
271	5	A = XOUT	DRSN 250
272		B = YOUT	DRSN 260
273		GO TO 2	DRSN 270
274	6	GO TO (7,8,11) IF	DRSN 280
275	7	CALL EDGPT(HALFX,HALFY,XOUT,YOUT,A,8,XEDG,YEDG)	DRSN 290
276		CALL PLOT(XEDG,YEDG,3)	DRSN 300
277		GO TO (17,18) IFLAG1	COST 312
278	17	CALL PLOT(XOUT,YOUT,2)	COST 313
279		GO TO 19	COST 315
280	18	CALL BROKEN(XOUT,YOUT,1)	COST 316
281	19	IF = 3	COST 31A
282		GO TO 5	DRSN 320
283	8	CALL PLOT(XOUT,YOUT,3)	DRSN 330
284		IF = 3	DRSN 340
285		GO TO 5	DRSN 350
286	9	CALL PLOT(0.0,0.0,3)	DRSN 360
287		RETURN	DRSN 370
288	11	GO TO (20,21) IFLAG1	COST 372
289	20	CALL PLOT(XOUT,YOUT,2)	COST 373
290		GO TO 22	COST 375
291	21	CALL BROKEN(XOUT,YOUT,1)	COST 374
292	22	IF = 3	COST 378
293		GO TO 5	DRSN 377
294	100	FORMAT(2F9.4)	DRSN 380
295		END	DRSN 390

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Subroutine GRDTH

This subroutine takes the geographical coordinates (expressed in degrees) of a point on the Earth's surface, converts these to radians, and uses MERC (q.v.) to convert to map coordinates. At the position on the map so indicated a symbol (selected from a range of fifteen possibles) is drawn and a label up to eight characters in length inserted to its right. An arbitrary number of such insertions and annotations may be made.

The operation of the subroutine is (c.f. listing):

Cards 1 to 150. Entry and notes; definition of variables:

~~COMMON~~ definition of useful variables.

Card 170. Reading of input data from a card (punched 2F10.4, I2, A8).

Card 180. 'End of Data' trap. ISYM is normally used to indicate the symbol to be plotted and lies in the range zero to fourteen inclusive. Negative ISYM is therefore used as a flag to cause an immediate return to the calling programme.

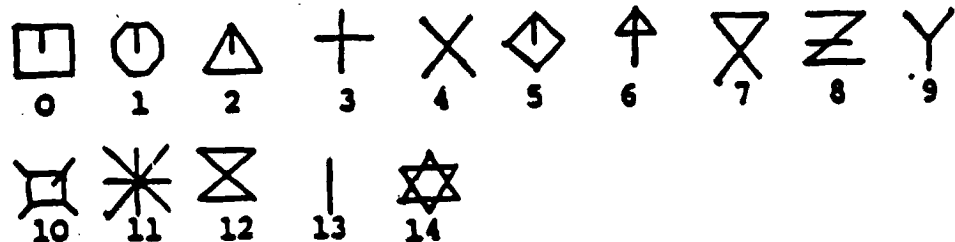
Cards 190 and 200. Conversion of supplied latitude and longitude to radians. The conversion factor ~~CONF~~ must be computed and placed in second place in ~~COMMON~~ by the main programme before calling this subroutine.

Cards 210 to 230. Computation of cartesian coordinates of the map point corresponding to the supplied geographical coordinates

relative to the geometrical map centre as origin. SCALE is introduced as an argument of the CALL. CENX and CENY will already have been computed and placed in the third and fourth places of COMMON by a previous call to @TLN.

Cards 235 and 236. Tests to determine whether the computed map coordinates lie beyond the map boundary. If so no attempt is made to annotate the map; instead, the next input card is read immediately.

Card 240. The symbol is drawn, the choice is made from the set illustrated below.



Card 250. The annotation is inserted.

Card 260. A skip is made back to label 1 so that a new data card may be read.

Cards 270 and 280. Return sequence. The pen is moved (up) back to the geometrical map centre before RETURN is executed.

#LISTING OF XC08.STOREF(1/) PRODUCED ON 29JUN77 AT 16.33.35

#OUTPUT BY LISTFILE IN 'XC08.MG?' ON 30JUN77 AT 12.00.22 USING 173

DOCUMENT STOREF

348	SUBROUTINE GROTH(CLAT,CLON,SCALE,HALFX,HALFY)	G0TH	1
349	C	G0TH	10
340	C THIS ROUTINE PLOTS GROUND TRUTH DATA POSITIONS AND VALUES ON A	G0TH	20
341	C PRE-PREPARED BASE MAP	G0TH	21
342	C	G0TH	30
343	C VARIABLES AND ARGUMENTS ---	G0TH	40
344	C CLAT,CLON = LATITUDE AND LONGITUDE OF GEOMETRICAL MAP CENTRE	G0TH	43
345	C (DEGREES).	G0TH	44
346	C CENX,CENY = CARTESIAN MAP COORDINATES OF GEOMETRICAL MAP	G0TH	50
347	C CENTRE RELATIVE TO ZERO LAT, ZERO LONG.	G0TH	51
348	C SCALE = MAP SCALE	G0TH	60
349	C HALFX = HALF MAP WIDTH	G0TH	65
350	C HALFY = HALF MAP HEIGHT	G0TH	66
351	C ALAT,ALON = LATITUDE AND LONGITUDE OF GROUND TRUTH DATA POINT	G0TH	70
352	C POSITION (ENTERED AS DEGREES BUT IMMEDIATELY	G0TH	71
353	C CONVERTED TO RADIANS)	G0TH	72
354	C ISYM = INTEGER (0,1,2,3,4) CONTROLLING SYMBOL DRAWN.	G0TH	80
355	C ISYM NEGATIVE INDICATES END OF GROUND TRUTH DATA	G0TH	81
356	C ALABEL(2) = LABEL TO BE ADDED TO MAP TO IDENTIFY GROUND TRUTH	G0TH	90
357	C DATA. MAXIMUM OF EIGHT SYMBOLS	G0TH	91
358	C XOUT,YOUT = CARTESIAN MAP COORDINATES OF GROUND TRUTH DATA	G0TH	100
359	C POINT	G0TH	101
360	C CONF = CONVERSION FACTOR DEGREES TO RADIANS	G0TH	110
361		G0TH	120
362		G0TH	130
363		G0TH	140
364		G0TH	150
365		G0TH	160
366	1 READ(3,100) ALAT,ALON,ISYM,ALABEL	G0TH	170
367	IF (ISYM.LT.0) GO TO 2	G0TH	180
368	ALAT = ALAT*CONF	G0TH	190
369	ALON = ALON*CONF	G0TH	200
370	CALL MERC(ALAT,ALON,XOUT,YOUT)	G0TH	210
371	XOUT = XOUT*SCALE - CENX	G0TH	220
372	YOUT = YOUT*SCALE - CENY	G0TH	230
373	IF (ABS(XOUT).GT.HALFX) GO TO 1	G0TH	235
374	IF (ABS(YOUT).GT.HALFY) GO TO 1	G0TH	236
375	CALL SYMBOL(XOUT,YOUT,0.2,ISYM,0.0,-1)	G0TH	240
376	CALL SYMBOL(999.0,999.0,0.16,ALABEL ,0.0,8)	G0TH	250
377	GO TO 1	G0TH	260
378	2 CALL PLOT(0.0,0.0,3)	G0TH	270
379	RETURN	G0TH	280
400	100 FORMAT(2F10.4,12, A8)	G0TH	290
401	END	G0TH	300

Subroutine MERC.

This subroutine takes the geographical coordinates (λ, β) of a point on the Earth's surface, and from them generates the cartesian coordinates (x, y) of an equivalent map point on a Mercator projection.

The geographical coordinates must be supplied in radians. The cartesian coordinates may be regarded as being returned in any convenient units of length. Both coordinate pairs are expected, or generated, referred to zero latitude, zero longitude as origin.

The basic equations are*:

$$x = R \cdot \beta \quad (1)$$

$$y = R \cdot \ln (\sec \lambda + \tan \lambda) \quad (2)$$

where λ = latitude (assumed ≥ 0.0)

β = longitude

R = radius of the terrestrial globe at the scale of the map.

For the purposes of this subroutine R is defined to be unity in the units of x and y , i.e. the true scale of the map must be established by multiplying the (x, y) delivered by a constant defined elsewhere.

The operation of the subroutine is (c.f. listing):

Cards 1 to 83. Entry and notes; definition of variables.

Card 90. ~~COMMON~~ definition for delivery of value of π .

Cards 100 to 130 and 160 to 190. These sections effectively apply equation (1) for the computation of x . It is so arranged that, no matter what the magnitude of the delivered longitude, β , x will lie in the range $-\pi \leq x \leq \pi$. The subroutine may therefore

only be applied with extreme caution to the preparation of maps where the meridian $\beta = \pm \pi$ lies within the boundary. For $\beta = \pm \pi$ beyond the map boundary no difficulty should be experienced.

Cards 140 and 145. These apply equation (2) for the computation of y from λ . Since for equation (2) to be meaningful $\lambda \leq 0.0$ card 140 effectively uses $|\lambda|$, while card 145 sets y negative if λ is negative.

Cards 150 and 200 RETURN and END.

* Steers, J.A., An Introduction to the Study of Map Projections, 14th Edn., p.146. University of London Press, 1965.

#LISTING OF :XC08.STOREF(1/) . PRODUCED ON 29JUN77 AT 14.33.35

#OUTPUT BY LISTFILE IN 'XC08.MOB' ON 30JUN77 AT 11.52.13 USING I33

DOCUMENT STOREF

27	SUBROUTINE MERC(PLAT,PLON,XOUT,YOUT)	MERC	1
28	C	MERC	10
29	C THIS ROUTINE COMPUTES THE CARTESIAN COORDINATES, ON A MERCATOR	MERC	20
30	C PROJECTION, OF SUPPLIED GEOGRAPHICAL POINTS. THE RADIUS OF THE BASIC	MERC	21
31	C SPHERE IS TAKEN TO BE UNITY.	MERC	22
32	C	MERC	30
33	C VARIABLES AND ARGUMENTS ---	MERC	40
34	C PLAT = LATITUDE OF THE SUPPLIED POINT (RADIAN)	MERC	41
35	C PLON = LONGITUDE OF THE SUPPLIED POINT (RADIAN)	MERC	42
36	C XOUT = X COORDINATE OF OUTPUT	MERC	43
37	C YOUT = Y COORDINATE OF OUTPUT	MERC	44
38	C PLON1 = TEMPORARY VARIABLE	MERC	45
39	C	MERC	50
40	C NOTE THAT IT IS ARRANGED THAT -PI,LE,XOUT,LE,PI . THERE IS NO	MERC	60
41	C FLAG TO INDICATE WHETHER PLON HAD TO BE ADJUSTED TO PLACE XOUT WITHIN	MERC	61
42	C THESE LIMITS. IN SOME CIRCUMSTANCES, THEREFOR, USE OF MERC NEAR	MERC	62
43	C PLON=PI MAY PRODUCE ODD EFFECTS WHERE SUCCESSIVE SCAN POINTS LIE ON	MERC	63
44	C OPPOSITE SIDES OF THIS MERIDIAN.	MERC	64
45	C	MERC	70
46	C	MERC	80
47	C	MERC	85
48	C COMMON PI	MERC	90
49	C PLON1 = PLON	MERC	100
50	1 IF(PLON1.GT.PI) GO TO 3	MERC	110
51	2 IF(PLON1.LT.-PI) GO TO 4	MERC	120
52	C XOUT = PLON1	MERC	130
53	C YOUT = ALOG((1.0 + SIN(ABS(PLAT)))/COS(PLAT))	MERC	140
54	C IF(PLAT.LT.0.0) YOUT = -YOUT	MERC	145
55	C RETURN	MERC	150
56	3 PLON1 = PLON1 - PI	MERC	160
57	C GO TO 1	MERC	170
58	4 PLON1 = PLON1 + PI	MERC	180
59	C GO TO 2	MERC	190
60	C END	MERC	200

Subroutine EDGPT

This subroutine determines the point on a map edge at which the line joining two successive scan-digitisation positions would cross that edge. One of the positions is assumed to be within the map boundary and the other outside it.

The subroutine computes the coordinates of the intersections between the line (produced if necessary) which joins the positions, and each of the edges (considered infinitely long) taken separately. It then selects the coordinates of that point which both lies between the positions and is not on an edge produced (see diagram).

The operation of the subroutine is (c.f.listing):

Cards 1 to 210. Entry and notes; definition of variables.

Card 220. Sets up three arrays, each length 4. X and Y will hold the cartesian coordinates of the four candidate intersections. IHOLD is used for housekeeping during the testing of the four candidates.

Cards 230 and 240. Initialisation of IHOLD to zero in all elements.

Cards 245 and 250. Computes the difference in the horizontal coordinates of the two supplied map points. In order to prevent a possible overflow at card 256 the value of DELX is tested, and, if it is very small, is fixed at a finite value.

Card 253. Computes the difference in the vertical coordinates of the two supplied map points.

Card 256. Computes the gradient of the line joining the two supplied map points.

Card 260 to 330. Computes the coordinates of the four candidate intersections and stores them in $X(i)$ and $Y(i)$, i from one to four.

Cards 340 to 370. A loop to test each of the candidate intersections as to whether or not it lies between the two supplied map points. Only the horizontal coordinates are required. The test parameter will be negative only for intersections lying between the supplied points and, since one point lies on and one off the map, no more than two such intersections can exist (c.f. diagram). If TEST is found to be negative or zero (point at edge) for any candidate intersection $IHOLD(i)$, for appropriate i , is set to one.

Cards 380 to 460. Final selection of the desired intersection. A pseudo DO loop is used. Card 400 causes a skip of the test routine if it has already been shown that the candidate intersection does not lie between the supplied points. Cards 410 and 420 initialise the output arguments with the coordinates of a candidate intersection in anticipation of a positive result. Cards 430 and 440 test whether the candidate under examination lies more than 0.01 mm outside the map boundary in either dimension. If so, it is known to be on an edge produced and hence not the desired intersection; the loop is repeated, therefore. If not, then it is taken to be the desired intersection and a RETURN executed at card 450. On the second pass through cards 430 and 440 their

presence is superfluous.

Card 460 closes the loop.

Card 600. End.

Note that cards 430 and 440 may cause erroneous output under certain conditions: If the line joining the two supplied points lies both very nearly parallel to, and very close to, an edge then it is possible that, on a first pass through 430 and 440, an intersection which lies on an edge produced but less than 0.01 mm from a corner will be passed and returned on the desired intersections. Since, under these conditions, the second candidate intersection, which will lie on the map boundary and can be at any distance from a corner, is not tested the output may be greatly in error. Such erroneous output should, due to the very special circumstances required, be extremely infrequent however.

 #LISTING OF :XC08.ETORFF(1/) PRODUCED ON 29JUN77 AT 16.33.35
 #OUTPUT BY LISTFILE IN :XC08.MOP' ON 30JUN77 AT 11.51.54 USING 133
 DOCUMENT STORE#

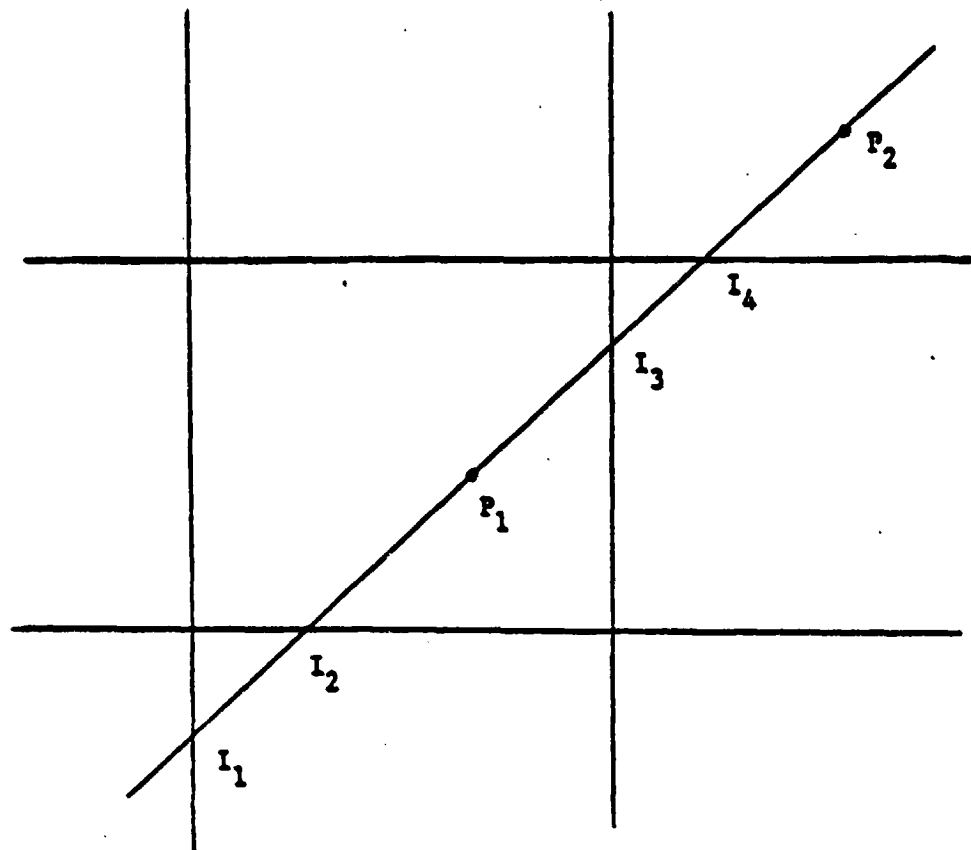
```

296            SUBROUTINE EDGPT(HALFX,HALFY,XOUT,YOUT,A,B,XEDG,YEDG)            EDPT    1
297 C            EDPT    10
298 C THIS ROUTINE COMPUTES THE CARTESIAN COORDINATES OF A POINT ON THE      EDPT    20
299 C INTERSECTION OF A STRAIGHT LINE JOINING SUCCESSIVE POINTS ON EITHER      EDPT    21
300 C SIDE OF A MAP BOUNDARY WITH THAT BOUNDARY                              EDPT    22
301 C            EDPT    30
302 C VARIABLES AND ARGUMENTS ---                                              EDPT    40
303 C            HALFX = HALF MAP WIDTH                                        EDPT    50
304 C            HALFY = HALF MAP HEIGHT                                       EDPT    60
305 C            XOUT = X COORDINATE OF CURRENT POINT                        EDPT    70
306 C            YOUT = Y COORDINATE OF CURRENT POINT                        EDPT    80
307 C            A     = X COORDINATE OF LAST POINT                          EDPT    90
308 C            B     = Y COORDINATE OF LAST POINT                          EDPT 100
309 C            XEDG,YEDG = OUTPUT                                            EDPT 110
310 C            GRAD = GRADIENT OF THE LINE JOINING (XOUT,YOUT) TO (A,B)      EDPT 120
311 C            X(4),Y(4) = STORAGE ARRAYS FOR THE CARTESIAN COORDINATES OF      EDPT 130
312 C                                                                              CANDIDATE EDGE POINTS                                              EDPT 131
313 C            INOLD(4) = STORAGE ARRAY FOR RECORDING RESULTS OF APPLICATION      EDPT 140
314 C                                                                              OF FACTOR 'TEST'.                                              EDPT 141
315 C            TEST = FACTOR APPLIED TO DETERMINE WHETHER A CANDIDATE EDGE      EDPT 150
316 C                                                                              POINT LIES BETWEEN THE CURRENT AND LAST POINTS.                                              EDPT 151
317 C                                                                              TEST NEGATIVE INDICATES YES, POSITIVE NO.                                              EDPT 152
318 C            I     = BOOK-KEEPING VARIABLE.                                EDPT 160
319 C            DELX,DELY = TEMPORARY VARIABLES                                EDPT 165
320 C            EDPT 170
321 C NOTE THAT IN PRINCIPLE THE ROUTINE MAY DELIVER AN ERRONEOUS OUTPUT      EDPT 180
322 C (IMPLYING THAT THE EDGEPOINT IS VERY NEAR A CORNER) UNDER CERTAIN      EDPT 181
323 C SPECIAL CONDITIONS. THIS SHOULD BE EXTREMELY INFREQUENT HOWEVER.      EDPT 182
324 C MANUAL FOR DETAILS.                                                        EDPT 183
325 C            EDPT 190
326 C                                                                              R.J.FRYER                                                                              4/3/77                                                                              EDPT 200
327 C            EDPT 210
328            DIMENSION X(4),Y(4),INOLD(4)                                      EDPT 220
329            DO 1 I=1,4                                                              EDPT 230
330            1    INOLD(I) = 0                                                        EDPT 240
331            DELX = XOUT - A                                                        EDPT 245
332            IF(ABS(DELX).LT.0.000001) DELX = 0.000001                        EDPT 250
333            DELY = YOUT - B                                                        EDPT 253
334            IF(ABS(DELY).LT.0.000001) DELY = 0.000001                        EDPT 254
335            GRAD = DELY/DELX                                                        EDPT 256
336            X(1) = HALFX                                                            EDPT 260
337            Y(1) = GRAD*(HALFX - A) + B                                        EDPT 270
338            X(2) = -HALFX                                                            EDPT 280
339            Y(2) = B - GRAD*(HALFX - A)                                        EDPT 290
340            X(3) = A + (HALFY - B)/GRAD                                        EDPT 300
341            Y(3) = HALFY                                                            EDPT 310
342            X(4) = A - (HALFY + B)/GRAD                                        EDPT 320
343            Y(4) = -HALFY                                                            EDPT 330
344            DO 2 I=1,4                                                              EDPT 340
345            TEST = (X(1) - A)*(X(1) - XOUT)                                    EDPT 350
346            IF(TEST.LE.0.0) INOLD(I) = 1                                        EDPT 360
347            2    CONTINUE                                                            EDPT 370
348            I = 0                                                                    EDPT 380
349            3    I = I + 1                                                            EDPT 390
350            IF(INOLD(I).LE.0) GO TO 4                                            EDPT 400
351            5    XEDG = X(I)                                                        EDPT 410

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352		YED6 = Y(I)	ENDT 420
353		IF(ABS(XED6).GT.(HALFX + 0.001)) GO TO 4	ENDT 430
354		IF(ABS(YED6).GT.(HALFY + 0.001)) GO TO 4	ENDT 440
355	6	RETURN	ENDT 450
356	4	GO TO (3,3,3,6) I	ENDT 460
357		END	ENDT 600

DIAGRAM



Intersection I_3 is the only one of the four candidates which both lies between P_1 and P_2 and is not on an edge produced. I_4 is between P_1 and P_2 but lies on an edge produced. I_2 is not on an edge produced, but does not lie between P_1 and P_2 . I_3 is therefore selected.

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