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COMPARISONS OF CLOUD COVER EVALUATED FROM LANDSAT IMAGERY AND METEOROLOGICAL STATIONS ACROSS THE BRITISH ISLES

ERTS Follow-on Programme Study No. 2962A

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Third Quarterly Report on Mesoscale Assessments of Cloud and Rainfall over the British Isles

by

Eric C. Barrett
M.Sc., Ph.D., F.R.G.S., F.R.Met.S., F.B.I.S.,

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I. INTRODUCTION

In the Second Quarterly Report (Barrett and Grant, 1976) attention was paid to the compilation of cloud photointerpretation keys for application to Landsat imagery. This was a necessary undertaking in preparation for later stages of this ERTS Follow-on Programme Study, concerned as it is with aspects of mesoscale weather patterns over the British Isles.

In this, the Third Quarterly Report, our attention turns to comparisons between evaluations of cloud cover based on Landsat image analysis and those observations of cloud recorded as part of the routine meteorological observing programme of stations reporting hourly to the British Meteorological Office. A map of these stations appeared in the First Quarterly Report (Barrett and Grant, 1975). All previous studies of which we are aware concerned with the reduction of satellite-derived cloud amounts to climatological information have considered data from meteorological satellites, including members of the American Tiros, Nimbus, Essa, Noaa and DMSP families. Landsat is important because the scale of its data is larger than that of the highest resolution data from meteorological satellites by about one order of magnitude. Although the Landsat coverage is much less frequent (eighteen daily as against once or twice daily, geostationary and geosynchronous satellites excepted) Landsat-based studies of cloud cover may have important implications for the design of future environmental satellite systems, and for the joint practices of analysis and utilisation of cloud imagery for meteorological and climatological applications.

The earlier comparisons between satellite and conventional data are divisible into two groups, based on the nature of the analytical procedures applied to the satellite data. These are as follows:

(a) Eyeball (subjective) methods. In these not only are the ground observations made by eye (which is the standard practice in the United Kingdom, as described in the Meteorological Observer's Handbook (HMSO, 1969), but also those assessments of cloud which are drawn from the satellite imagery. The products include schematized cloud charts (nephanalyses) which include an evaluation of cloud cover, whether the base data are visible (Harris and Barrett, 1975) or infrared images (Barrett and Harris, in press), and tabulated cloud amount statistics prepared in analagous fashion to the conventional assessments of cloud amount by trained, experienced analysts. Examples of studies involving cloud amount mapping from nephanalyses compiled for routine meteorological use are those reported by Clapp (1964), Godshall (1971) and Sadler (1969). Examples of statistical tabulations include those by Sherr et al., (1968) and Malberg (1973).

(b) Machine-assisted (partially objective) methods. Here the satellite image analyst is aided by some apparatus which reduces the reliance on human skill. Such methods have mostly involved some form of video processing or densitometry through which areas above a pre-selected brightness threshold are automatically summed. Examples of such studies include those by Miller (1971) (based on visible imagery) and Coburn (1971) (based on infrared imagery). Many factors complicate the selection of the brightness threshold. These include:

i) The waveband investigated;

ii) The characteristics and performance of the sensor system;

iii) The data path from sensor to display facility (including the passage through preprocessing and processing procedures);

iv) The characteristics of the display facility;

v) The time of year of each observation;

vi) The time of day of each observation;

vii) The dominant cloud type;

viii) Background brightness effects;

ix) User requirements; and

x) Operator performance.

Any or all of these may induce variance within a single set of results and/or differences between sets of results. In any operational scheme designed to run through extended periods of time very careful controls would be essential in every case.

With the experimental development of automatic devices for cloud cover assessment from the ground two other groups of techniques for the comparison of satellite and in situ ("ground truth") observations may become possible. These would relate the new objective surface observations to the satellite data evaluated by either eyeball or machine-assisted methods. Examples of studies of automated ground observation systems include the computer simulation exercises carried out by Duda et al., (1973) and the experimental use of a radiometer detector for cloud cover by Werner (1973).

II. TECHNIQUES

Surface observations

As this study is concerned with comparisons of cloud cover statistics derived from Landsat II imagery with those from ground

LANDSAT COVERAGE OF THE BRITISH ISLES:
Tabulation of Individual Frames

(see also Table 2 in Barrett and Grant, 1975, and Table 1 in Barrett and Grant, 1976)

DAY Since Launch	DATE 1975	ORBIT NUMBER	Frame No.s 4 6	5 7	TIME H : M : S	CO-ORDS OF CENTRE LATITUDE	LONGITUDE
2286	4 NOVEMBER	3984	085 141	113 169	10 : 59 : 00	N 59 : 57	W06 : 29
"	"	"	086 142	114 170	10 : 59 : 30	N 58 : 34	W07 : 27
"	"	"	087 143	115 171	10 : 59 : 50	N 57 : 11	W08 : 21
"	"	"	088 144	116 172	11 : 00 : 20	N 55 : 48	W09 : 11
2287	5 NOVEMBER	3998	138 176	157 195	11 : 07 : 20	N51 : 35	W12 : 54
"	"	"	MSG 177	MSG MSG	11 : 07 : 40	N50 : 11	W13 : 34
2288	6 NOVEMBER	4012	026 094	060 128	11 : 10 : 30	N59 : 59	W09 : 19
"	"	"	027 095	061 129	11 : 11 : 00	N58 : 37	W10 : 16
"	"	"	028 096	062 130	11 : 11 : 20	N57 : 14	W11 : 10
2290	8 NOVEMBER	4040	159 185	172 198	11 : 22 : 00	N59 : 59	W12 : 13
"	"	"	135 205	170 240	11 : 22 : 20	N58 : 37	W13 : 11
2295	13 NOVEMBER	4109	113 169	141 197	10 : 08 : 30	N55 : 49	E03 : 41
"	"	"	114 170	142 198	10 : 09 : 00	N54 : 25	E02 : 53
"	"	"	115 171	143 199	10 : 09 : 20	N53 : 02	E02 : 07
"	"	"	116 172	144 200	10 : 09 : 50	N51 : 38	E01 : 25
"	"	"	117 173	145 201	10 : 10 : 10	N50 : 14	E00 : 44
"	"	"	118 174	146 202	10 : 10 : 40	N48 : 49	E00 : 06
2312	30 NOVEMBER	4346	006 080	043 117	10 : 03 : 30	N53 : 08	E03 : 40
"	"	"	007 081	044 118	10 : 03 : 50	N51 : 44	E02 : 57
"	"	"	008 082	045 119	10 : 04 : 20	N50 : 20	E02 : 16
"	"	"	009 083	046 120	10 : 04 : 40	N48 : 55	E01 : 37

DAY Since Launch	DATE 1975	ORBIT NUMBER	Frame Nos		TIME	CO-ORDS OF CENTRE	
			4 6	5 7	H : M : S	LATITUDE	LONGITUDE
2333	21 DECEMBER	4639	009 067	038 096	10:21:20	N50:22	W02:04
"	"	"	010 068	039 097	10:21:40	N48:57	W02:43
2337	25 DECEMBER	4695	001 069	035 103	10:43:20	N53:08	W06:27
"	"	"	002 070	036 104	10:43:50	N51:43	W07:10
"	"	"	003 071	037 105	10:44:10	N50:19	W07:50
"	"	"	004 072	038 106	10:44:40	N48:55	W08:28
2340	28 DECEMBER	4737	169 205	187 223	11:00:30	N53:05	W10:43
"	"	"	170 206	188 224	11:01:00	N51:41	W11:26
"	"	"	171 207	189 225	11:01:20	N50:16	W12:08
	1976						
2353	10 JANUARY	4918	136 206	171 241	10:31:20	N54:20	W02:56
"	"	"	137 207	172 242	10:31:50	N52:56	W03:41
"	"	"	138 208	173 243	10:32:10	N51:31	W04:23
"	"	"	139 209	174 244	10:32:40	N50:07	W05:04
"	"	"	140 210	175 245	10:33:00	N48:42	W05:43
2365	22 JANUARY	5085	236 270	253 287	09:58:00	N50:07	E03:29
"	"	"	237 271	254 288	09:58:30	N48:43	E02:51
2366	23 JANUARY	5099	004 070	037 103	10:02:50	N52:56	E03:26
"	"	"	005 071	038 104	10:03:20	N51:32	E02:44
"	"	"	006 072	039 105	10:03:40	N50:07	E02:03
"	"	"	007 073	040 106	10:04:10	N48:43	E01:25

DAY Since Launch	DATE 1976	ORBIT NUMBER	Frame Nos. 4 6	5 7	TIME H : M : S	CO-ORDS OF CENTRE LATITUDE	LONGITUDE
2369	26 JANUARY	5141	333 349	341 357	10 : 18 : 50	N57 : 03	E01 : 31
"	"	"	334 350	342 358	10 : 19 : 10	N55 : 40	E00 : 41
"	"	"	335 351	343 359	10 : 19 : 40	N54 : 17	W00 : 07
"	"	"	336 352	344 360	10 : 20 : 00	N52 : 52	W00 : 52
"	"	"	269 335	302 368	10 : 20 : 30	N51 : 09	W01 : 45
"	"	"	270 336	303 369	10 : 21 : 00	N49 : 46	W02 : 25
2371	28 JANUARY	5169	101 161	131 191	10 : 31 : 10	N54 : 15	W02 : 59
"	"	"	102 162	132 192	10 : 31 : 30	N52 : 51	W03 : 44
"	"	"	103 163	133 193	10 : 32 : 00	N51 : 27	W04 : 26
"	"	"	104 164	134 194	10 : 32 : 20	N50 : 03	W05 : 07
"	"	"	105 165	135 195	10 : 32 : 50	N48 : 39	W05 : 46
2372	29 JANUARY	5183	093 151	122 180	10 : 35 : 30	N58 : 29	W01 : 50
"	"	"	094 152	123 181	10 : 36 : 00	N57 : 06	W02 : 44
"	"	"	073 131	102 160	10 : 36 : 20	N55 : 42	W03 : 34
"	"	"	074 132	103 161	10 : 36 : 50	N54 : 19	W04 : 22
"	"	"	075 133	104 162	10 : 37 : 10	N52 : 55	W05 : 07
"	"	"	076 134	105 163	10 : 37 : 40	N51 : 31	W05 : 50
"	"	"	077 135	106 164	10 : 38 : 00	N50 : 07	W06 : 31
"	"	"	078 136	107 165	10 : 38 : 30	N48 : 43	W07 : 10
2373	30 JANUARY	5197	026 078	052 104	10 : 41 : 20	N58 : 27	W03 : 20
"	"	"	001 053	027 079	10 : 41 : 40	N57 : 03	W04 : 14
"	"	"	002 054	028 080	10 : 42 : 00	N55 : 39	W05 : 04
"	"	"	003 055	029 081	10 : 42 : 30	N54 : 16	W05 : 52
"	"	"	004 056	030 082	10 : 43 : 00	N52 : 53	W06 : 38
"	"	"	005 057	031 083	10 : 43 : 20	N51 : 29	W07 : 20
"	"	"	006 058	032 084	10 : 43 : 50	N50 : 05	W08 : 01

DAY Since Launch	DATE 1976	ORBIT NUMBER	Frame Nos		TIME	CO-ORDS OF CENTRE	
			4 6	5 7	H : M : S	LATITUDE	LONGITUDE
2373	30 JANUARY	5197	007 059	033 085	10:44:10	N48:40	W08:40
2376	2 FEBRUARY	5239	MSG 170	152 188	10:58:50	N57:01	W08:37
"	"	"	135 171	153 189	10:59:20	N55:38	W09:27
"	"	"	136 172	154 190	10:59:40	N54:14	W10:14
"	"	"	137 173	155 191	11:00:10	N52:50	W10:59
"	"	"	138 174	156 192	11:00:30	N51:26	W11:41
"	"	"	139 175	157 193	11:01:00	N50:02	W12:22
"	"	"	140 176	158 194	11:01:20	N48:37	W13:00

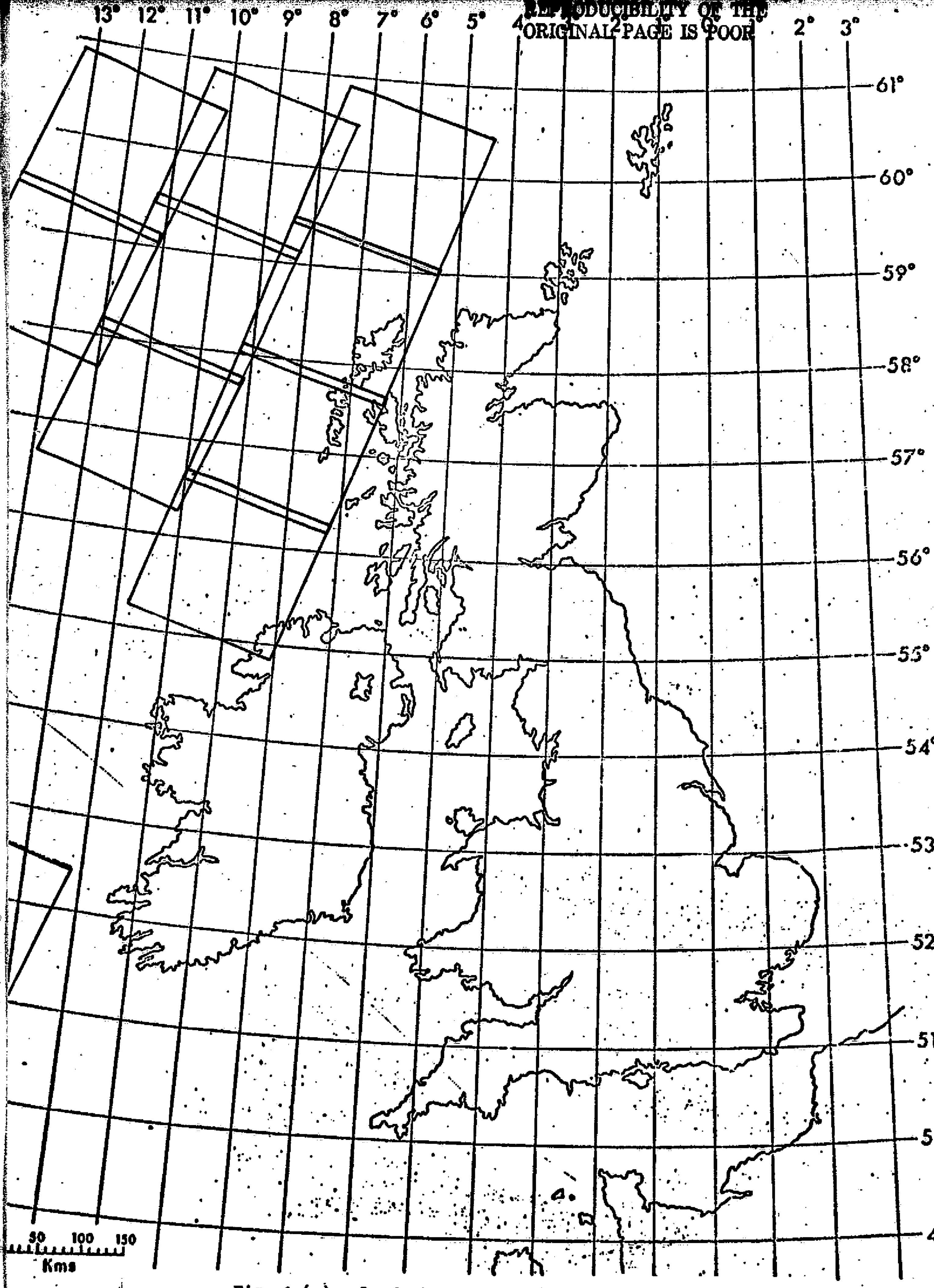

Fig. 1 (a): Landsat coverage of the British Isles, Cycle 15,
24 Oct. - 10 Nov., 1975

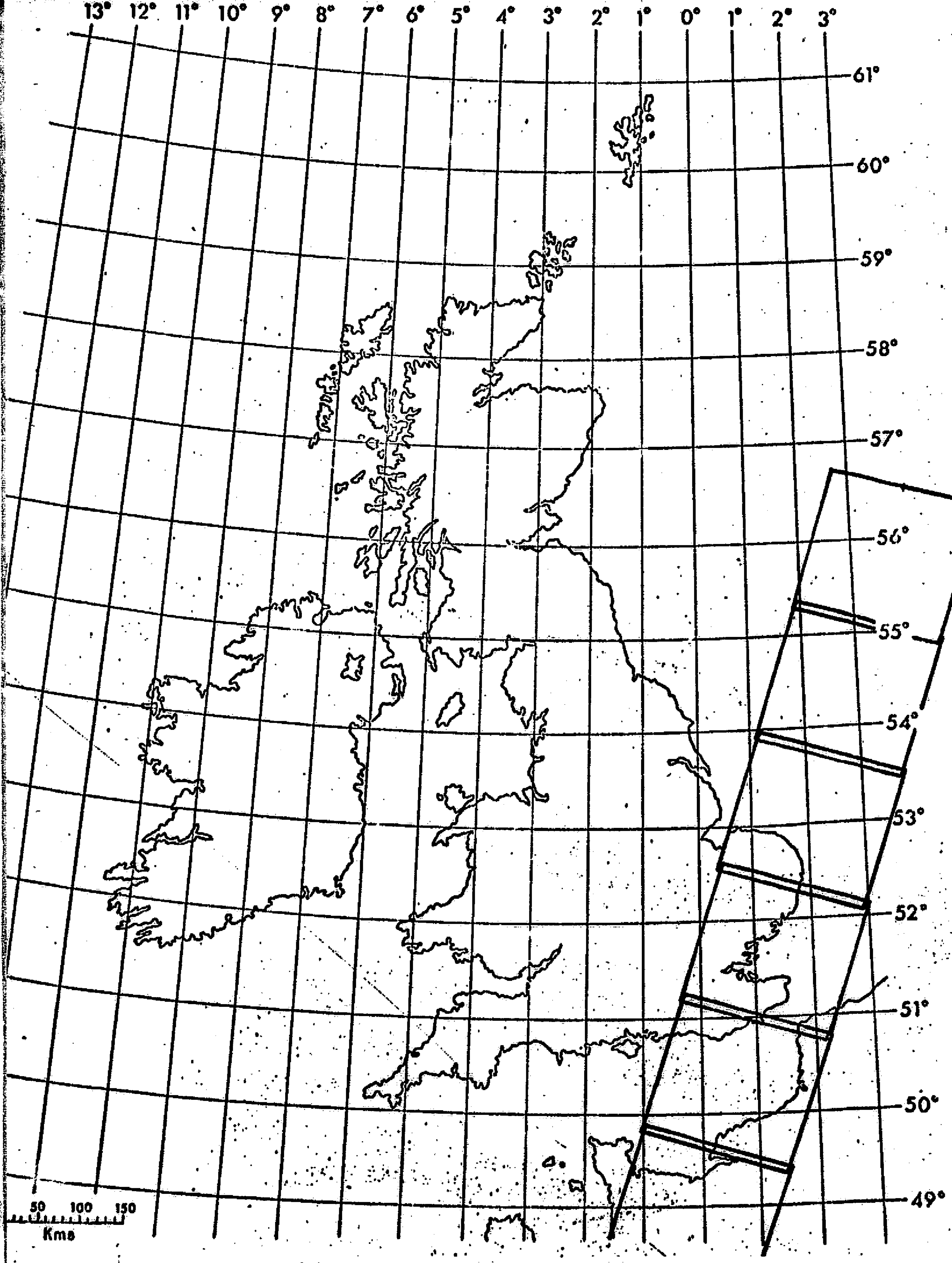

Fig. 1 (b): Landsat coverage of the British Isles, Cycle 16, 11 Nov. - 28 Nov., 1975.

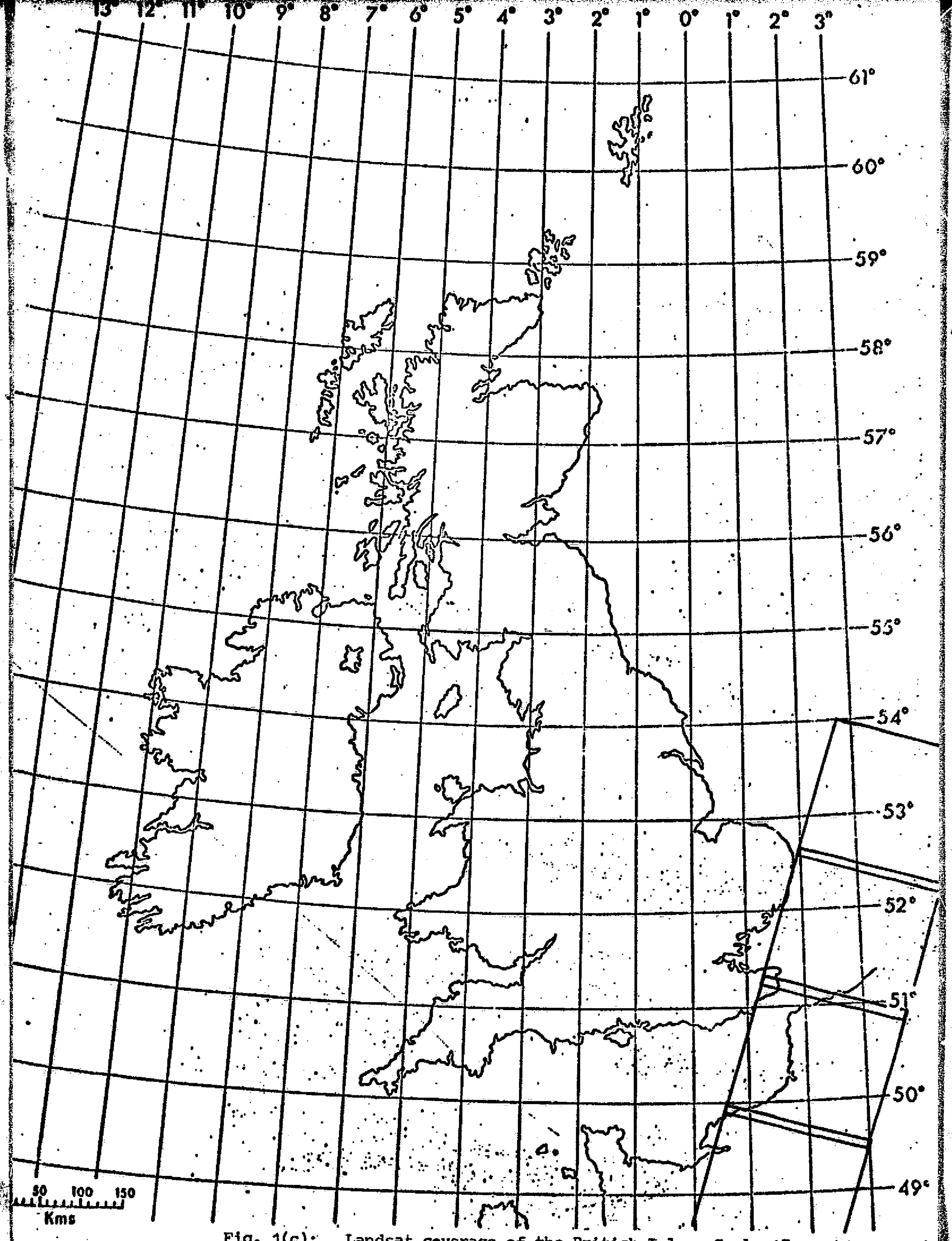

Fig. 1(c): Landsat coverage of the British Isles, Cycle 17, 29 Nov. - 16 Dec., 1975

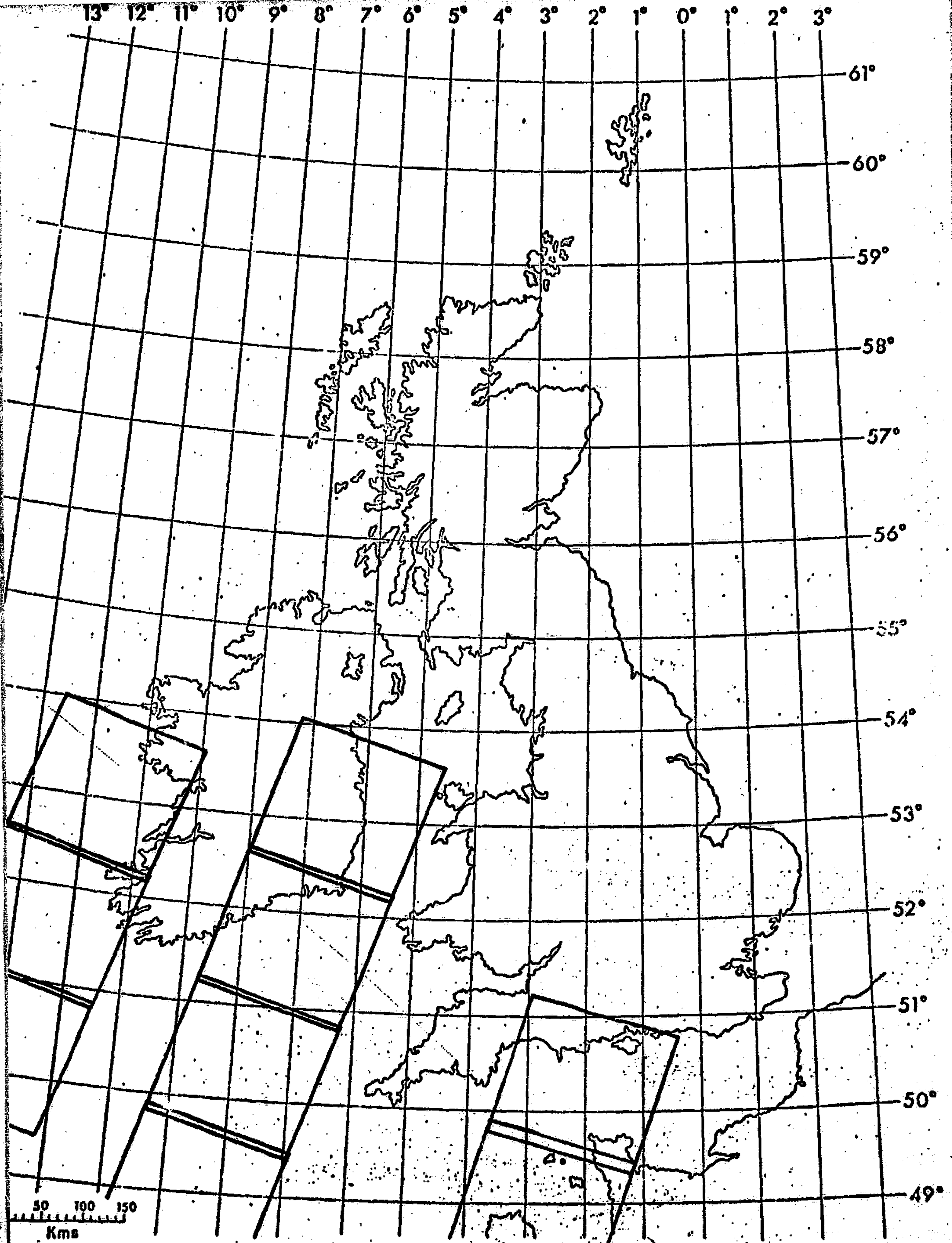

Fig. 1 (d): Landsat coverage of the British Isles, Cycle 18, 17 Dec., 1975 - 3 Jan., 1976.

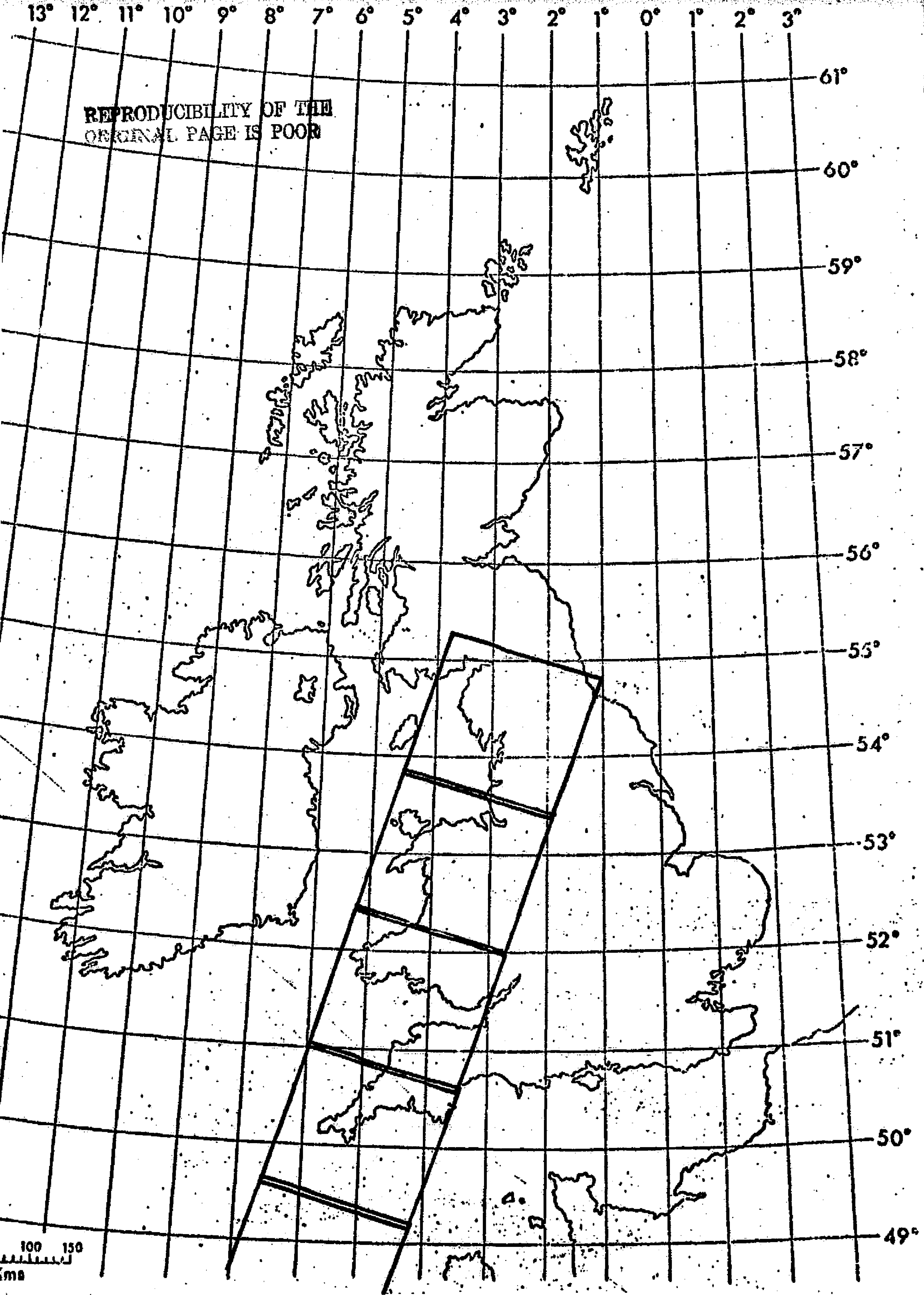

Fig. 1 (e): Landsat coverage of the British Isles, Cycle 19,
4 Jan. - 21 Jan., 1976.

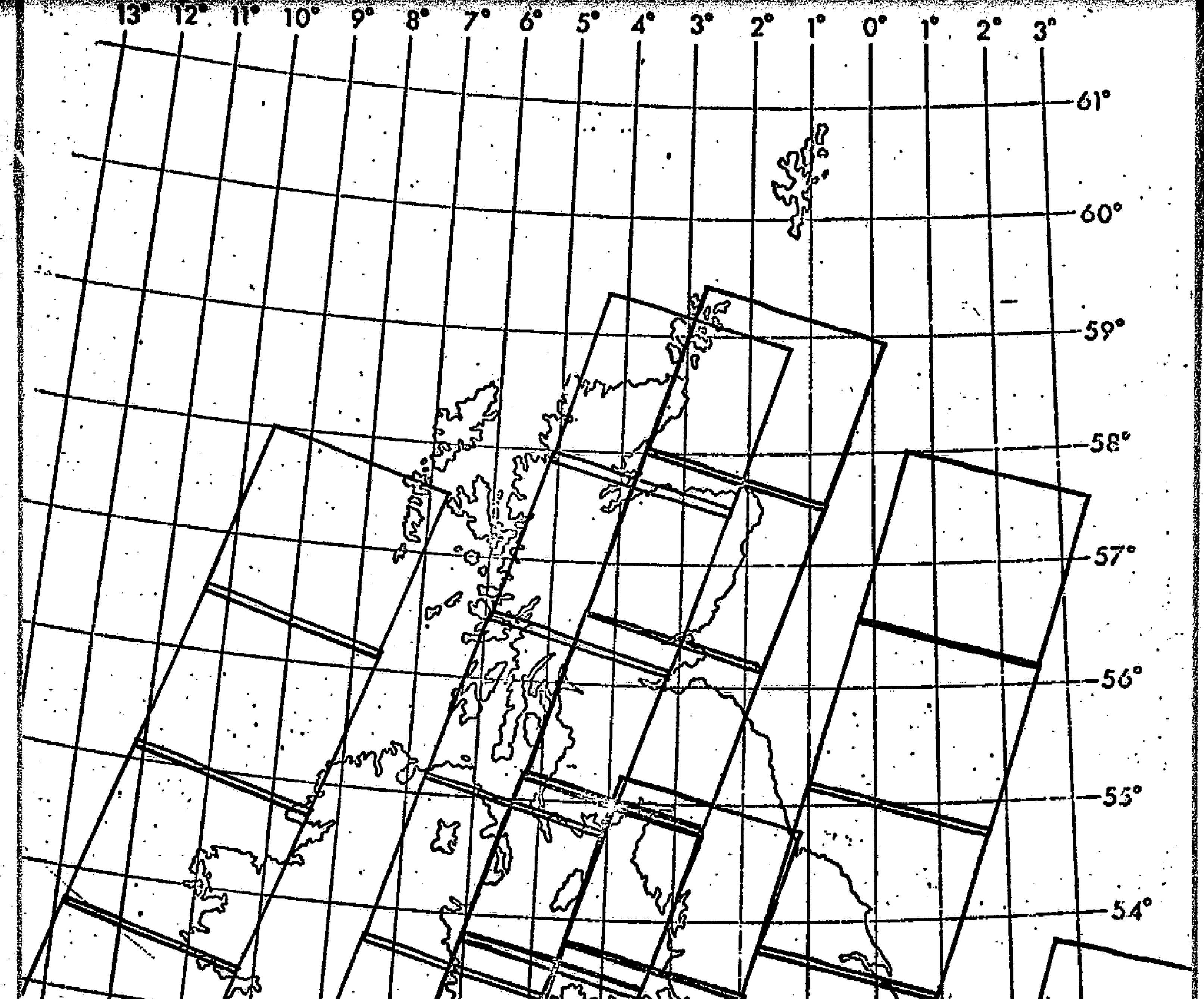

Fig. 1 (f): Landsat coverage of the British Isles, Cycle 20, 22 Jan. - 8 Feb. 1976.

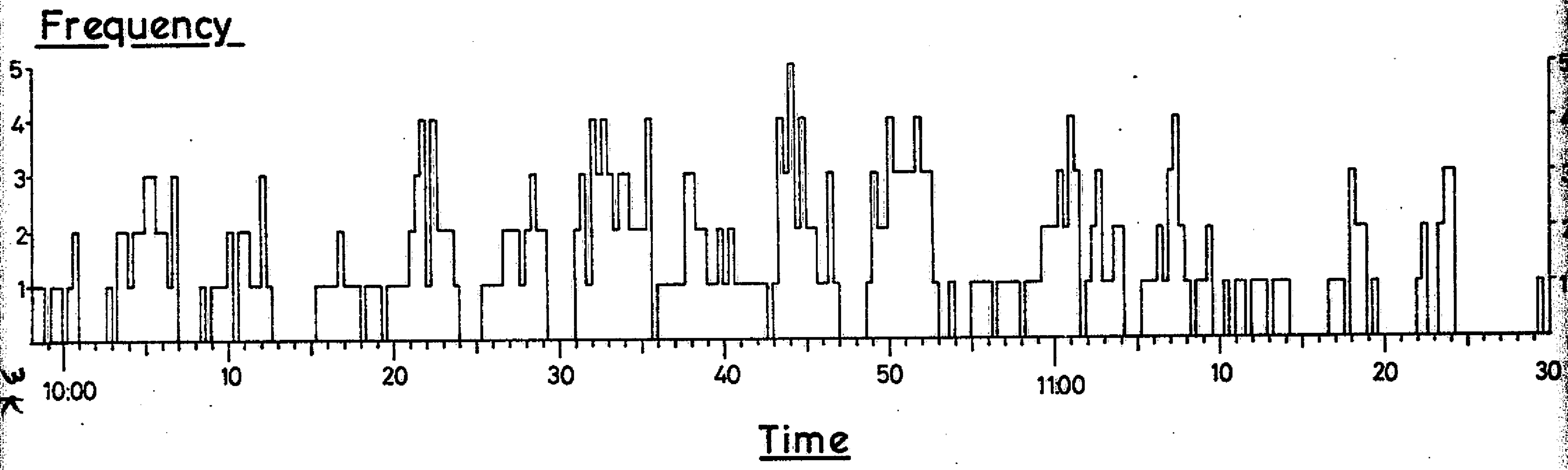

Fig. 2: Distribution of the imagery through time.

observations, a brief note is in order firstly concerning the surface observation technique.

In the U.K. cloud amount is reported in oktas (eighths), with the scale of values extending from 0, when the sky is completely cloudless, to 8 when the sky is completely overcast. The complete scale is listed below (HMSO, 1969).

TABLE 2.

The U.K. code for reporting cloud amount

Code Figure	Amount of Cloud
0	Sky completely cloudless
1	Trace to 1/8
2	1/8+ to 5/16-
3	5/16 to 7/16-
4	7/16 to 9/16
5	9/16 to 11/16-
6	11/16 to 7/8-
7	7/8 to 8/8- (overcast with openings)
8	Sky completely overcast
9	Sky obscured or cloud amount impossible to estimate.

Note: (+) and (-) signs indicate "slightly more than", and "slightly less than", respectively.

The surface observer is instructed to estimate the cloud amount from a viewpoint which "commands the widest possible view of the sky", and he (she) should be "careful to give equal weight to the areas around the zenith and those at a lower angular elevation".

The Choice of Landsat imagery for cloud cover assessment studies

The Landsat MSS imagery consists of individual frames, each frame being comprised of 4 individual images, corresponding to the 4 separate wavebands of the multispectral scanner. It was decided that, for the purposes of this study, the examination of the imagery in a single waveband would suffice to provide estimates of satellite observed cloud amount. Band 5 imagery (0.6-0.7μm) was chosen as this usually provides better contrast between background features and clouds than Band 4. The impression of improved contrast in Band 5 gained through simple eyeball observations is supported by a quantitative study by Danko (1974). He measured the contrast of a variety of cloud types against different land and water backgrounds in both Bands 4 and 5. The measured contrast in Band 5 was in each case more than one and a half times the contrast in Band 4.

The location of surface stations on Landsat imagery

One of the initial tasks in this study was to identify the positions of the surface observation stations on the Landsat imagery. The British Meteorological Office provided latitude and longitude coordinates for the stations concerned. (See Fig.3, Barrett and Grant 1975).

A map of the British Isles was prepared at the same scale as that of the Landsat imagery (1 : 3,369,000). This was achieved by photographically reducing a map at a scale of 1 : 2,500,000 to the correct scale. The projection of the original map (and similarly the final, reduced product) was a Transverse Mercator, constructed by the U.K. Ordnance Survey. The surface stations were then marked on the final product.

It has been shown by Colvocoresses (1973) that the MSS bulk processed imagery has its own unique projection, termed the "Space Cylindrical Strip Perspective". However, it has been established that, in fitting the imagery to a Transverse Mercator projection, only small positional errors are introduced thereby (generally less than 1 : 1,000), and this was deemed sufficiently accurate for our purposes.

The Landsat MSS imagery is provided with latitude and longitude marks on the outside edge of the image writing area at intervals of 30 arc minutes. It has been noted that the latitude and longitude marks are often in error by up to 5 or 6 kms., sometimes more (e.g. Mott and Chismon, 1975). This could result in our station circles being displaced by up to about 20% of their areas. As the cloud cover in most of the images was substantial, it was not possible to use visible landmarks to improve the "fit" of the imagery to the map of surface station locations. However, it is felt that any errors incurred as a result should be randomly distributed and therefore not substantially affect the final results.

Using the latitude and longitude marks, it was possible to fit the images to the map of surface station locations. For each image, a thin sheet of clear plastic was overlayed, and the positions of the stations falling within the image area were marked on the plastic by small dots. To facilitate the accurate relocation of the overlay small dots were applied to the plastic, coincident with the centres of the four registration marks (crosses) provided at the corners of each image.

The choice of station circle size

The next phase of the study was to determine on the Landsat imagery, the size and shape of the area which would be used to extract cloud amount statistics. A circular area, centred at the station location, was felt to represent best on the image the surface observer's view of the sky. The surface observer has a very limited field of view in comparison with the satellite. The maximum radius of his vision is about 50 kilometres, depending on topography, visibility and local obstructions. However, this maximum value is rarely achieved in practice, and, frequently, a very much smaller field of view is observed. It had been hoped at an earlier stage in this study, that we would have been able to take account of factors such as obstructions to the fields of view from individual surface observation positions, and then to assess their effects on cloud amount estimation, (Barrett and Grant, 1975). However, further consideration of the matter, including discussions with surface observers and senior officials at the U.K. Meteorological Office led us to abandon such a course. One of the major problems was that many surface stations are situated at, or near, military establishments. Permission for access to these for the purpose of sketching the silhouettes of buildings and other installations would not have been easily or rapidly obtained.

Having decided thus that the shape of the data extraction area was to be circular, we next considered the question of its size. Similar studies have utilised circles of various sizes to provide comparisons with surface observations.

Studies by Sherr et al. (1968), Glaser et al. (1968) and Greaves (1973) all used circles with a diameter of 1° of latitude (approximately 111 kilometres), to extract cloud amount statistics from Nimbus II and Essa imagery. A study by Barnes and Chang (1968) examined the effect of varying the circle diameter. They used circles with diameters of $\frac{1}{2}^{\circ}$, 1°, 2° and 3° of latitude. These diameters correspond to distances of 56, 111, 222 and 333 kilometres respectively on the ground. They found that the $\frac{1}{2}^{\circ}$ diameter circle provided the closest approximation to values of cloud amount registered by surface observers. They concluded that "...for climatological purposes, satellite cloud amounts extracted for circular areas of about $\frac{1}{2}^{\circ}$ latitude diameter can be considered to form a sample compatible with surface observations".

It was decided therefore to employ a circular area with a diameter of 50 kilometres to extract cloud amount statistics from the Landsat imagery.

The sample size.

The total number of frames available at the commencement of the study was 328 (Landsat cycles 1 - 20). However, many of the frames portrayed sea areas, with consequently no compatible surface observations. Therefore, the number of suitable frames was reduced to 131. The number of surface observations available for each frame varied, from one to a maximum of six. It was decided to include only those surface observations around which a complete circle of 50 km. radius could be drawn within the image area. In this way a number of additional problems were avoided. Thus the total number of satellite image observations available for comparison with surface observations was 288. At a later stage all occasions when code figure 9 was reported at the surface were withdrawn from the population on account of the ambiguity of this surface observation. This reduced the number of comparisons to 282.

Methodology

As noted in the introduction, in similar studies of this type both eyeball and machine-assisted methods have been employed. This study included both approaches. The work was undertaken in two phases. The first phase was machine-assisted, using a

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Quantimet 720 Image Analysing Computer at ADAS, Cambridge. The second phase was an eyeball investigation of the same images, using a microfilm reader to enlarge the 70mm images to a comfortable viewing size. The two sets of results were then compared with the corresponding surface observations of cloud amount extracted from the hourly charts provided by the Meteorological office.

Phase 1 : Machine-assisted method

The Machine

The Quantimet 720 Image Analysing Computer used in this study was manufactured by Cambridge Instruments and is owned by the Air Photography Unit of the Agricultural Development Advisory Service (ADAS), Ministry of Agriculture.

The input peripheral of the instrument is an epidiascope connected to a vidicon camera. Illumination of the images was by fluorescent tubes with a diffuse screen intervening. The lens attached to the vidicon in this study had a focal length of 51 mm (f1.9), providing the largest magnification of the original image while retaining on the display screen a circular analysis area equivalent to a circle of 50 km diameter (Plate 2). As large a magnification as possible was chosen (approximately 7 times the original) in order that as much of the original image detail should be retained. The vidicon in the system was specifically designed for image analysis purposes and incorporates a 720-line scan, with no interlacing, and a very slow scan rate of 10.6 scans per second.

The image is scanned, digitised and displayed on a cathode ray tube (CRT) screen. Image editing is possible on the machine used for this study, and, using a light-pen, the operator can

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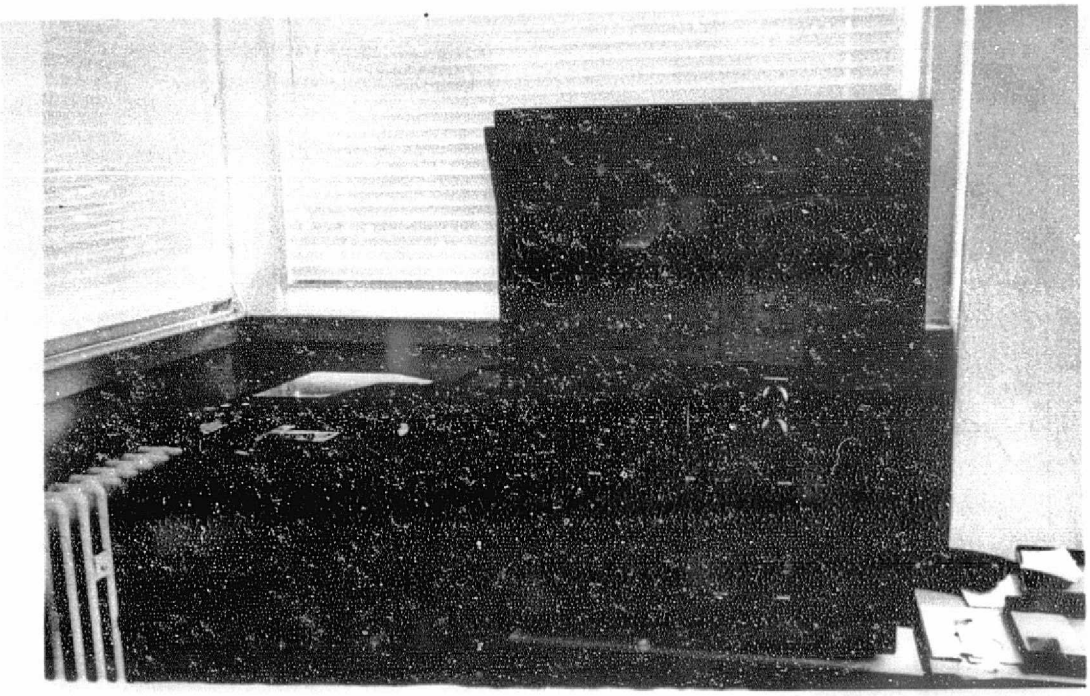

(b)

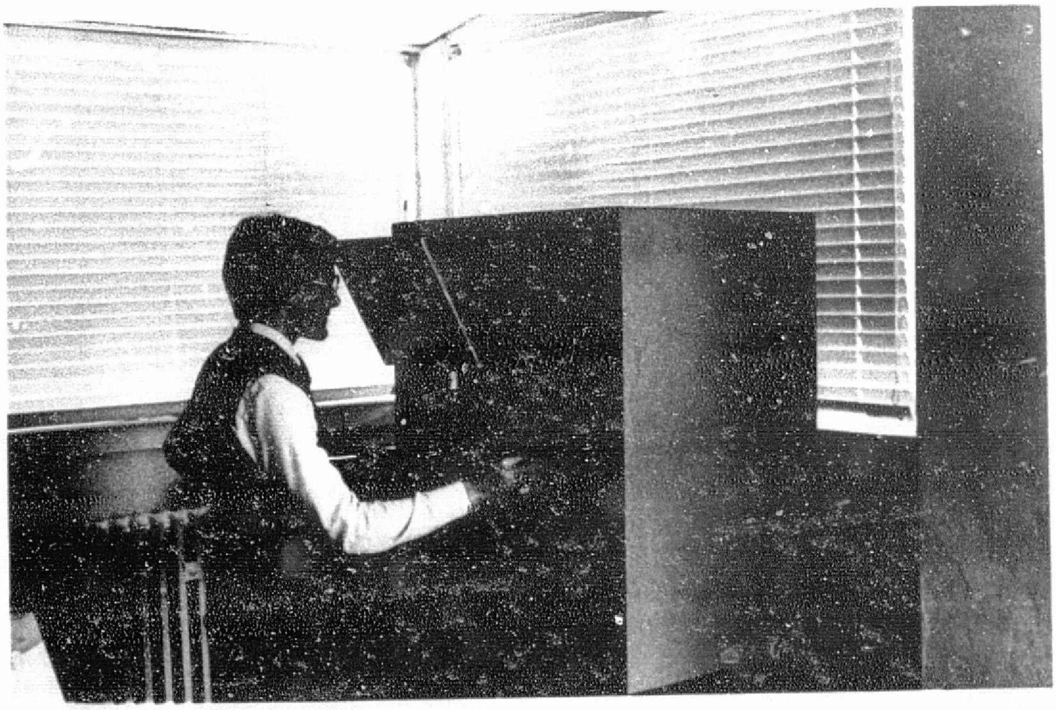

PLATE 1: The Quantimet 720 image analysis system at ADAS, Cambridge:

(a) The main module (right) displaying Landsat 2 image input from epidiascope (left); and

(b) the operator engaged in a man-machine interaction process.

(Courtesy, Ministry of Agriculture).

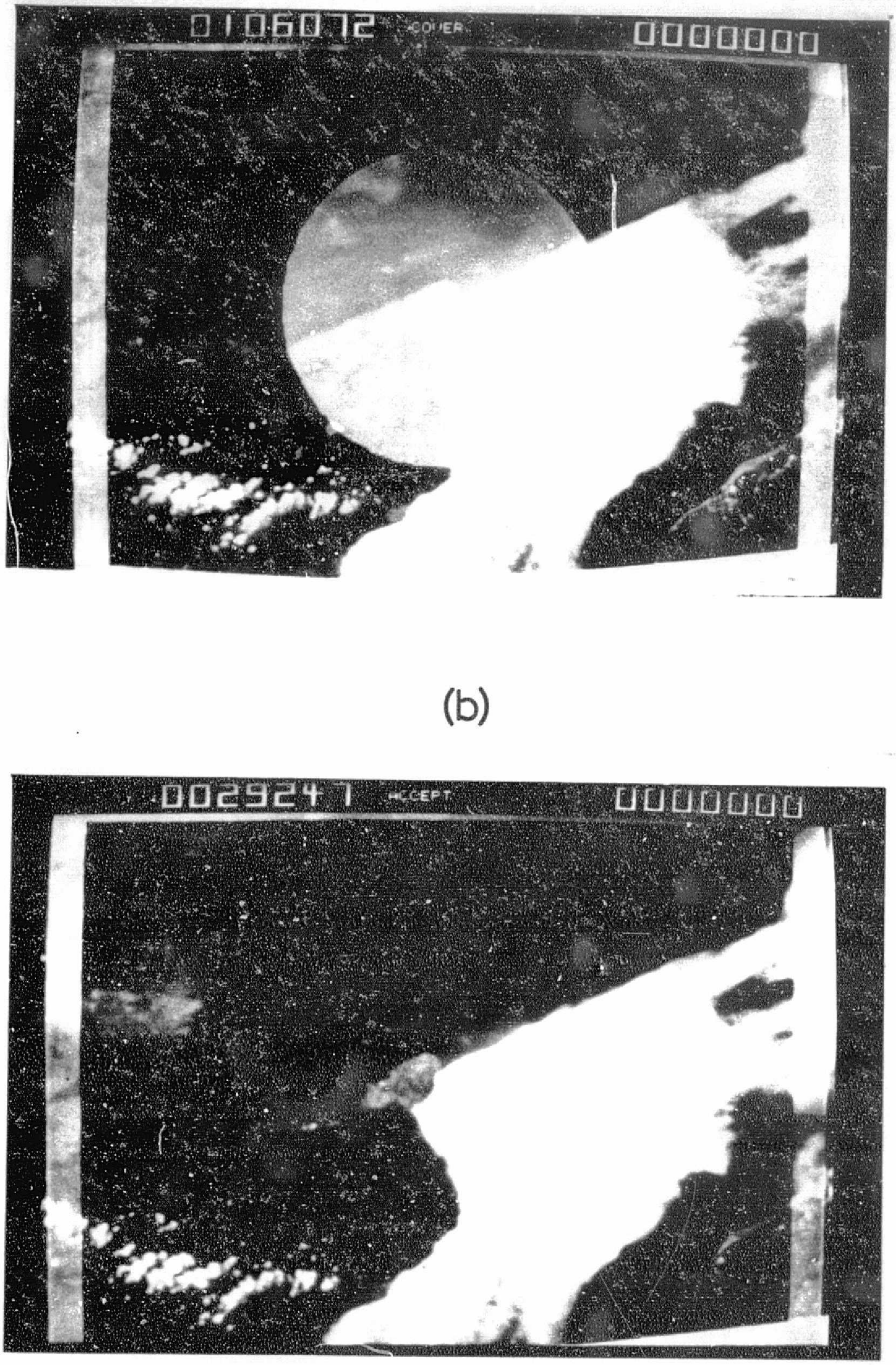

PLATE 2: Stages in the process of estimating cloud area on a Landsat 2 image: (a) The detection area (grey disc) is positioned for Manston (Kent); the number of picture points is indicated on the menu at top left. (b) The area within the detection circle above the cloud brightness threshold has been summed in terms of picture points. The result is indicated at top left.

(Courtesy, Ministry of Agriculture).

interact with the machine in a variety of ways. The major advantage to this study of the image editing function was the possibility of outlining a circular analysis area on the CRT screen (corresponding to a 50 km diameter circle on the original image). Without the image editing function, the analysis area would have been restricted to a square or rectangular area.

The full CRT screen display contains 500,000 picture points (p.p.). All area measurements made in this study are therefore in terms of p.p. which were later transformed to give the correct cloud amount values in eighths of the area investigated. The circular analysis area drawn by the light pen was approximately 53 mm. in diameter, and consisted of some 106,072 p.p. Each p.p. therefore corresponds to an area of approximately 0.02 km^2 or approximately a square of sides 136 metres. The pixel size on the original image is approximately 79 metres square, and therefore some loss of resolution may have occurred through this system.

The other major component of the machine used for this study was the "<u>ID Auto-Detector</u>". This module selects or "detects" features displayed on the CRT screen, on the basis of differences in colour or contrast. Thus to detect the required features, they must have, in general, a grey-scale difference from everything not requiring detection.

A "whiter-than" detection mode was adopted in this study. This provides detection of all features brighter than the grey-scale level (or brightness threshold) selected. The grey scale is divisible into 1000 divisions, and is infintely variable: threshold values are selected by turning a marked dial. The maximum resolution of the system is 1p.p.

Theshold setting is the most important source of systematic error in the 720 machine (Imanco, 1971). On reasonably well defined features the use of the "flicker" method (Fisher, 1971) should not give a systematic error greater than 1p.p. in defining the feature perimeter, but the detection process may add to that a random error of ± 1p.p. (Imanco, 1971). This means that area measures, as used in this study, may have an error of 1 p.p. multiplied by the feature perimeter. This could be quite large where many, small features (e.g. cumulus cells) are being detected. However, for the purposes of this study it was felt that these errors would be minimal in the majority of cases. In cases where many small features were detected, for example when small cumulus cells predominate, resulting errors should not be significant, as we are working finally to the nearest 1/8 of the detection circle (13,259 p.p.).

Area measurement on the machine is defined as "the number of picture points in the field falling inside the detected features".

Detailed discussion of the machine and its various modules can be found in Fisher (1971) and Imanco (1971).

Operational Procedure

(a) Each time the machine was switched on, at the start of a working period, it was allowed at least half an hour to "warm up" to allow the vidicon time to settle down.

(b) After applying a shade correction (automatically executed by the machine), the images were placed in the same central optical paths in the focal plane of the vidicon. This ensured that any systematic errors remaining, after shading correction in the machine, would be similar for each image.

(c) The iris of the vidicon lens was set approximately half open, in order to achieve the best combination of dynamic range and sensitivity. The lens was manually focussed on the lettering of a Landsat image, this providing a sharply-defined, high contrast object.

(d) A brightness threshold reading was taken of step 8 on the 15-step grey scale on each Landsat image. This was to check for differences in photographic processing etc. undergone by each image. Two threshold values were taken, the first when any part of the step was just detected, the second when complete detection had been achieved.

(e) An area not coincident with that to be later analysed within a station circle(s) was chosen, and a cloud/no cloud brightness threshold value was obtained using the "flicker" method. Usually one value was adequate for all the clouds on a particular image. However, on certain occasions two or more different thresholds had to be established for application to different station circles. This was necessitated mainly by differences in background brightness over an image and/or changes in cloud type. As the solar elevation angle alters throughout the year, cloud brightness alters also; consequently it was not possible to select single threshold values for different cloud types to be used on all images.

(f) The plastic overlay providing station location information was then carefully aligned with the Landsat image, and each individual station location was centred on the circle displayed on the CRT screen. The overlay was removed before each area measurement was made.

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(g) Using the "accept" mode on the image editor, and the cloud threshold value(s) established previously, an area measurement of the cloud amount in each circle on an image was made. The Quantmet 720 has memories which store the results from 16 separate measurements, from 16 successive scans. This allows the mean values to be taken. In this way errors resulting from noise are reduced. Each mean value was in p.p. The following conversions were applied to make the data compatible with surface observations.

TABLE 3.

Quantimet p.p.-to-cloud okta conversion Table

Code No.	p.p.
0	1 - 13,259
2	13,260 - 33,147
3	33,148 - 46,406
4	46,407 - 59,666
5	59,667 - 72,925
6	72,926 - 92,812
7	92,813 -106,071
8	106,072

(h) At the completion of the initial data set, some replicate readings were taken in the same manner described above. Images were chosen at random and retested. In most cases both the step 8 and the cloud/no cloud brightness threshold values were different, usually within the range of 1 to 20 on the 1000 division scale. However, the calculated areas were usually similar, the maximum discrepancy being 1 okta in a few cases. Thus, although absolute brightness threshold values are difficult to obtain, broad-category area measurements can be replicated in an overwhelming majority of cases.

Phase II : Eyeball Study

The same set of images used in Phase I of the study was examined some 10 days later by an eyeball technique. A time gap was left in order that the observer should not be biassed by remembering previous results.

Each image was examined on a microfilm reader, with a magnification of 14 times. A circle corresponding to the 50 km - diameter circle representing the field of view of the surface observer was placed on the screen to provide the area inside which cloud amount would be estimated. Each station location on the image overlay of each image was placed so as to coincide with the centre of that circle. An eyeball assessment of the cloud amount inside the circle was then made; the dominant cloud type was also noted. The dominant cloud type was assessed under the following categories:

(i) Cumulonimbiform
(ii) Cumuliform
(iii) Stratiform
(iv) Stratocumuliform
(v) Cirriform
(vi) No cloud
(vii) Mixed - when 2 or more cloud types were equally dominant.

A number of replicate readings were taken (approx. 25%). Over 90% yielded identical results. No discrepancy was greater than 1 okta.

Finally, the values of cloud amount observed at the surface stations were extracted from the hourly charts provided by the Meteorological Office. As the time of the Landsat imagery used in this study varied from 10:00 G.M.T. to 11:30 G.M.T. both 10:00 and 11:00 charts were used, and the surface data extracted from the chart nearest in time to that of the imagery. In no case was the time difference greater than 30 minutes. This is probably smaller than in any previous satellite/ground truth comparison; it is certainly much smaller than in most. All 3 sets of results were then compiled into contingency tables.

III. RESULTS

The detailed results are presented in the form of contingency tables (Figs.3 to 8) and frequency graphs (Fig.9). The first contingency table (Fig.3) sums the results of all three observational methods compared for all the dominant cloud categories used in this study. Perhaps the most striking feature of Figure 3 is the similarity of tables (a) and (b). It can be seen that, with respect to both the satellite image observer and the Quantimet, the surface observer consistently overestimates the cloud amount. This is especially apparent in the middle of the okta scale. At the upper end of the scale (7 to 8 oktas) the satellite image observer and the Quantimet tend to overestimate with respect to the ground observer. When table (c) of Figure 3 is examined, it can be seen that the results obtained by the satellite image observer and estimations based on the Quantimet are similar with respect to the whole okta scale. Some notable erratics remain, but these are isolated, individual instances, for which there are usually obvious reasons.

The findings above are interesting when compared to the findings of previous studies. The majority of studies of this

(a)

Surface observer

v

Satellite image observer

Satellite image observer

Surface observer

	0	1	2	3	4	5	6	7	8	Σr
0	14	1		1						16
1	8	21	2	1						32
2	4	3	2	1						10
3		7	2			1				10
4		5	2	1						8
5		3		4	2	2		1	1	13
6			5	3	8	4	2	9	1	32
7			1	1	7	7	6	39	27	88
8						1	1	7	64	73
Σc	26	40	14	12	17	15	9	56	93	282

(b)

Surface observer

v

Quantimet

Quantimet

Surface observer

	0	1	2	3	4	5	6	7	8	Σr
0	14	1			1					16
1	12	15	4	1						32
2	5	2	2	1						10
3	1	6	2				1			10
4		1	6	1						8
5		2	2		4	2	2		1	13
6		1	3	2	5	7	8	3	3	32
7		1		3	4	4	17	29	30	88
8						1	1	10	61	73
Σc	32	29	19	8	14	14	29	42	95	282

(c)

Satellite image observer

v

Quantimet

Quantimet

Satellite image observer

	0	1	2	3	4	5	6	7	8	Σr
0	26									26
1	6	27	7							40
2			11	3						14
3		1	1	4	5	1				12
4					7	8	2			17
5		1			2	4	8			15
6				1			8			9
7						1	11	37	8	57
8								5	87	92
Σc	32	29	19	8	14	14	29	42	95	282

Fig. 3: All Cloud Types.

(a)

Surface observer

v

Satellite image observer

	Satellite image observer									
Surface observer	0	1	2	3	4	5	6	7	8	Σ_r
0				1						1
1	2	3	1							6
2			1	1						2
3		1	1							2
4		1	1							2
5		1		2	2	1		1	1	8
6			1	1	4	2	2	7		17
7				1	2	2	3	20	14	42
8						1		3	37	41
Σ_c	2	6	5	6	8	6	5	31	52	121

(b)

Surface observer

v

Quantimet

	Quantimet									
Surface observer	0	1	2	3	4	5	6	7	8	Σ_r
0					1					1
1	2	2	2							6
2			1	1						2
3		1	1							2
4			2							2
5		1			3	2	1		1	8
6				1	2	3	6	3	2	17
7				1	2		8	15	16	42
8						1		4	36	41
Σ_c	2	4	6	3	8	6	15	22	55	121

(c)

Satellite image observer

v

Quantimet

	Quantimet									
Satellite image observer	0	1	2	3	4	5	6	7	8	Σ_r
0	2									2
1		4	2							6
2			4	1						5
3				2	4					6
4					3	4	1			8
5					1	2	3			6
6							5			5
7							6	20	5	31
8								2	50	52
Σ_c	2	4	6	3	8	6	15	22	55	121

Fig. 4: Stratocumuliform clouds dominant.

(a)

Surface observer

v

Satellite image observer

Satellite image observer

Surface observer

	0	1	2	3	4	5	6	7	8	Σ_r
0		1								1
1	2	15	1							18
2	3	2	1							6
3		3	1							4
4		3	1							4
5		2		2		1				5
6			3	1		1		1	1	7
7			1		1	2	1	11	6	22
8									4	4
Σ_c	5	26	8	3	1	4	1	12	11	71

(b)

Surface observer

v

Quantimet

Quantimet

Surface observer

	0	1	2	3	4	5	6	7	8	Σ_r
0		1								1
1	4	13	1							18
2	3	2	1							6
3		3	1							4
4		1	3							4
5		1	2		1		1			5
6			3		1	1	1		1	7
7				1	1	1	5	6	8	22
8								1	3	4
Σ_c	7	21	11	1	3	2	7	7	12	71

(c)

Satellite image observer

v

Quantimet

Quantimet

Satellite image observer

	0	1	2	3	4	5	6	7	8	Σ_r
0	4									4
1	2	21	3							26
2			7	1						8
3	1		1		1	1				4
4					1					1
5					1	1	2			4
6							1			1
7							4	6	2	12
8								1	10	11
Σ_c	7	21	11	1	3	2	7	7	12	71

Fig. 5: Cumuliform clouds dominant.

(a)

Surface observer

v

Satellite image observer

Satellite image observer

Surface observer

	0	1	2	3	4	5	6	7	8	Σ
0										0
1		1		1						2
2	1									1
3										0
4										0
5										0
6				1						1
7					2	1		3	4	10
8								4	22	26
Σ	1	1	0	2	2	1	0	7	26	40

(b)

Surface observer

v

Quantimet

Quantimet

Surface observer

	0	1	2	3	4	5	6	7	8	Σ
0										0
1			1	1						2
2	1									1
3										0
4										0
5										0
6		1								1
7					1	1	1	3	4	10
8								5	21	26
Σ	1	1	1	1	1	1	1	8	25	40

(c)

Satellite image observer

v

Quantimet

Quantimet

Satellite image observer

	0	1	2	3	4	5	6	7	8	Σ
0	1									1
1			1							1
2										0
3		1		1						2
4					1	1				2
5							1			1
6										0
7								6	1	7
8								2	24	26
Σ	1	1	1	1	1	1	1	8	25	40

Fig. 6: Stratiform clouds dominant.

15d

(a)

Surface observer

v

Satellite image observer

Satellite image observer

Surface observer

	0	1	2	3	4	5	6	7	8	Σ_r
0										0
1	4	2								6
2		1								1
3		2								2
4										0
5										0
6								1		1
7							1	1	3	5
8										0
Σ_c	4	5	0	0	0	1	1	4	0	15

(b)

Surface observer

v

Quantimet

Quantimet

Surface observer

	0	1	2	3	4	5	6	7	8	Σ_r
0										0
1	6									6
2	1									1
3	1	1								2
4										0
5										0
6						1				1
7		1		1			1	2		5
8										0
Σ_c	8	2	0	1	0	1	1	2	0	15

(c)

Satellite image observer

v

Quantimet

Quantimet

Satellite image observer

	0	1	2	3	4	5	6	7	8	Σ_r
0	4									4
1	4	1								5
2										0
3										0
4										0
5		1								1
6				1						1
7						1	1	2		4
8										0
Σ_c	8	2	0	1	0	1	1	2	0	15

Fig. 7: Cirriform clouds dominant.

(a)

Surface observer

v

Satellite image observer

Satellite image observer

Surface observer

	0	1	2	3	4	5	6	7	8	Σ_r
0										0
1										0
2										0
3		1								1
4		1		1						2
5										0
6			1		2					3
7					1		1	1	1	4
8							1		1	2
Σ_c	0	2	1	1	3	0	2	1	2	12

(b)

Surface observer

v

Quantimet

Quantimet

Surface observer

	0	1	2	3	4	5	6	7	8	Σ_r
0										0
1										0
2										0
3		1								1
4			1	1						2
5										0
6				1	1	1				3
7						1	1	1	1	4
8							1		1	2
Σ_c	0	1	1	2	1	2	2	1	2	12

(c)

Satellite image observer

v

Quantimet

Quantimet

Satellite image observer

	0	1	2	3	4	5	6	7	8	Σ_r
0										0
1		1	1							2
2				1						1
3				1						1
4					1	2				3
5										0
6							2			2
7								1		1
8									2	2
Σ_c	0	1	1	2	1	2	2	1	2	12

Fig. 8: Cumulonimbiform clouds dominant.

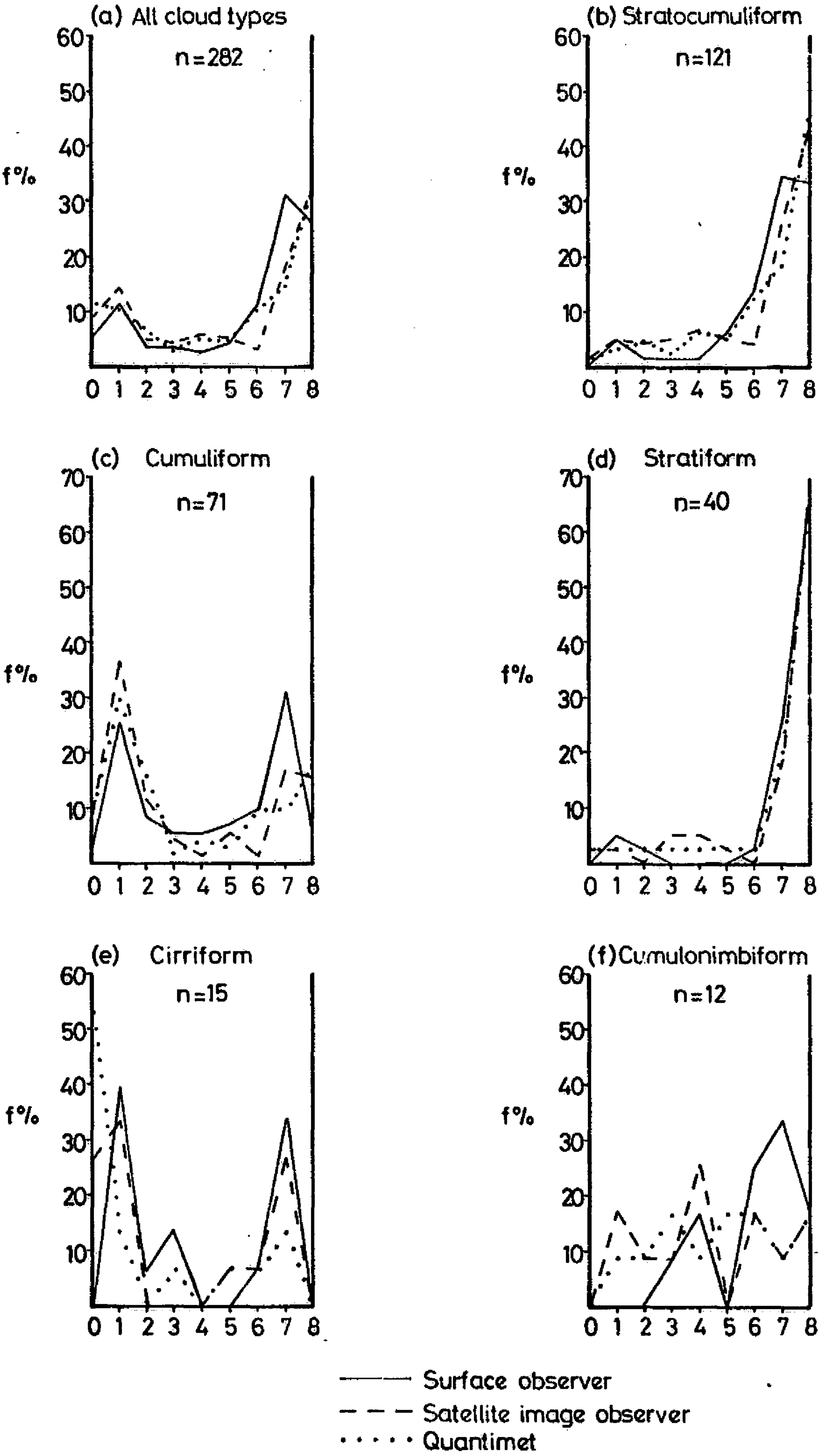

Fig. 9: Frequency Distributions.

type (including those by Clapp (1964), Barnes et al. (1967), Cooley et al. (1967) and Malberg (1973))have found that the ground observer usually overestimates the cloud amount with respect to satellite observations. A number of reasons have been advanced for this discrepancy. These can be divided into 2 groups, the first concerned with surface estimations, the second with satellite imagery estimations of cloud amount.

(a) Surface estimations:

The surface observers view of the sky is complicated by the fact that his perspective changes continuously from the zenith to the horizon. A numoer of different proposals have been made in the literature (summarised by Neuberger, 1951) as to the apparent shape of the sky, but all agree that the perspective is flattened to a greater, or lesser, extent. The amount of apparent flattening cannot be accounted for simply, as it is not only related to physical conditions in the atmosphere, but also to psychological factors which vary among observers. It certainly varies with both cloud type and cloud height (Miller and Neuberger, 1945). Because of this apparent flattening, approximately half the sky is below an elevation angle of 30°. Therefore, the instruction to the surface observer to "give equal weight to the areas around the zenith and those at a lower elevation angle" (HMSO, 1969) seems somewhat inappropriate.

Because of the flattening of perspective, in scattered cloud situations, the observer will see the sides, as well as the bases of clouds, and he may have difficulty in distinguishing gaps in the cloud, especially when these are at low elevation angles. For these reasons, the surface observer may frequently overestimate the cloud amount.

(b) Satellite image estimations:

In satellite imagery, the perspective problem is generally of minor importance, because of the orbiting altitude of the satellite. In Landsat imagery, for example, the maximum angle of view from the vertical is nearly 6°. A problem frequently encountered in estimating cloud amounts in satellite imagery is that of limited resolution of the sensor. In most previous studies, the imagery used was not of sufficient resolution to allow the detection of small cloud elements. Therefore, the satellite estimates would frequently be too low on occasions when small cumulus cells were present. The same discrepancy, but of different sign occurs when the cloud amount tends towards 8/8. Here small gaps in the clouds may not be resolved and therefore overestimates may occur.

With Landsat imagery, the resolution is sufficiently good to minimise the above problems. However, although small darker, patches in the cloud can be seen, the image analyst must decide whether these are due to shadows or actual gaps. It was found in this study that on numerous occasions, gaps were not identified as such, so causing the overestimation of cloud amount in the satellite imagery at the upper end of 0 to 8 scale.

Despite the good resolution of the MSS, it still proved extremely difficult to identify thin cirrus clouds reported at surface stations. This was especially true on the Quantimet, where the cirrus (if seen) was frequently much darker than many background features.

The remaining contingency tables, Figures 4 to 8 break down the data to facilitate comparisons for individual cloud types.

Fig.4. Stratocumuliform cloud. The overall pattern which emerges in Fig.4 is similar to that for all cloud types (Figure 3). Again the surface observer overestimates, especially in the middle (4 to 5 okta region) of the scale, while at the upper-end of the scale, the estimations from the satellite imagery are the greater.

Fig.5. Cumuliform clouds. The usual pattern emerges. Overestimation by the surface observer is more concentrated at the lower end of the scale, around 1 to 2 oktas. Again the relationship between the satellite image observer and the Quantimet is fairly consistent.

Fig.6. Stratiform clouds. Here there are few estimates in the middle of the scale. Those we obtained are greater for the surface observer. At the upper end of the scale (7 to 8 oktas) where the majority of estimates occur, good agreement is seen between all 3 methods.

Fig.7. Cirriform clouds This shows the difficulty of cirrus detection, especially by the Quantimet. Both the surface and satellite image observers overestimate with respect to the machine.

Fig.8. Cumulonimbiform clouds. This cloud type was not frequently encountered. However, the general trend of overestimation at the surface is seen from the tables.

Figure 9 shows frequency graphs. Each shows the frequency (as a %) on the ordinate, and the 0 to 8 cloud amount scale on the abscissa. The graph for all cloud types (a), reveals an interesting feature. It is that the surface observers indicate two maxima, at 1 and 7 oktas - this type of distribution is generally known as 'V' shaped. The satellite image observer

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shows two maxima also at 1 and 8 oktas. This distribution has been termed 'J' shaped (Barrett, in press). The Quantimet also reveals two maxima, at 0 and 8 oktas - this is known as a'U' shaped distribution.

Figure 9(b) shows the frequency of Stratocumuliform cloud. The predominance of high cloud amounts associated with this cloud type is striking. This is similarly seen in (d) for Stratiform. Figure 9(c) shows cumuliform cloud and two maxima are noted at 1 and 7 oktas. Graphs (e) and (f) appear complex, and this is probably due to the low numbers of observations which make up the graphs, combined with the fact that % frequencies were used.

IV. ACCOMPLISHMENTS

This stage of the study has confirmed our initial supposition that Landsat data could be analysed to provide useful data on cloud amount, and that useful light would be thrown thereby on the performance of the ground observer of this aspect of the state of the sky. This study, in comparison with previous studies of a similar nature using data from meteorological satellites, has benefitted greatly from the much higher resolution data provided by Landsat. This has permitted us to consider not only the overall performance of the surface observer in estimating total cloud cover, but also his performance under different sky conditions. The most important implications of the results outlined in Section II are discussed in the final section, Recommendations and Conclusions.

V. PROBLEMS

The chief problem hindering the study as a whole continues to be the uncertainty over the Landsat data coverage being provided for this study. As the maps of imagery for the late autumn and early winter months reveal (Figs. 1(a)-(f)) data-coverage has become very sparse for the later months of the study period. Arrangements were made with NASA for complete coverage of the study region to be obtained from March 19th-25th following the suggestions to this end in the Second Quarterly Report. This was the only cycle for which such a promise was available in advance, although at the time of writing (June 4th, 1976) the imagery for that period have not yet been received. Special arrangements were made with several U.K. meteorological facilities for the acquisition of supporting in situ observations in addition to the data routinely available from the hourly-reporting meteorological stations and continuous-recording rainfall stations. These facilities were as follows:

(a) The Meteorological Research Flight, based at Farnborough (Hants.). Although it was planned originally that the Flight would obtain data contemporaneously with the overflight of Landsat on both March 19th and 23rd, in the event it was only available on the first of these dates due to unserviceability of the aircraft.

(b) The weather radar at Edgbaston Observatory, University of Birmingham. Some PPI and RHI data were obtained to coincide with the time of Landsat imaging over the Midlands on March 21st-23rd.

(c) Weather radar systems operated by the Royal Radar Establishment in North Wales to cover the Welsh border areas and North Wales on March 21st.

The data obtained will be compared in due course with such Landsat imagery as we eventually receive. Whilst it is hoped that useful results emerge it is unfortunate that such additional data could not have been acquired for a number of different synoptic situations, and that more notice of the certainty of Landsat coverage was not given to enable us to plan scientifically the structure of this study.

VI. DATA QUALITY AND DELIVERY

The quality and resolution of the data received has continued to be high in both respects. Data delivery still runs some three months behind the dates of Landsat overflight.

VII. RECOMMENDATIONS AND CONCLUSIONS

The chief conclusion to emerge from this stage of the mesoscale assessment of cloud over the British Isles is that satellites imaging (like Landsat) with sufficiently high resolution in the visible region of the electromagnetic spectrum can provide better estimates of total cloud cover than are obtained in general from ground observing stations, especially when the sky is partly covered with cloud. It appears that, in the middle of the okta-scale, the ground observer tends to overestimate the amount of cloud, for reasons discussed in the text. His performance seems to be least acceptable where cumuliform or stratocumuliform clouds are dominant. These conclusions are of significance to the acquisition of cloud cover data at ground observing stations.

Increasing attention is being paid to cloud cover in models of both the heat and hydrological budgets of the Earth (see GARP, 1975). It would seem very likely that satellites imaging once or twice daily with a resolution equal to, or little worse, than the Landsat systems could aid significantly the mapping of cloud cover for both meteorological and climatological purposes. It was observed in the Second Quarterly Report that the identification of cloud type can be completed with much more confidence using Landsat imagery than imagery currently available from operational satellites, e.g. the 4.5 km resolution SR data or even the 0.9 km resolution VHRR data obtainable from satellites of the Noaa family. To that fact we may now add the complementary conclusion that the assessment of total cloud cover can be undertaken with more accuracy using Landsat imagery than ground observations; we hope soon to undertake comparisons between Landsat imagery and imagery from the Noaa-VHRR and DMSP-HR (0.6 km resolution) imaging systems also. Thus we may be able to suggest the optimum resolution for cloud data for studies of all types down to local regional/ meso-scales. The result should be of significance to those engaged in planning and designing Earth observation satellite systems for future operation and application.

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