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AN EVALUATION OF MSS P-FORMAT DATA REGISTRATION

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16. ABSTRACT

Twelve Landsat scenes of the P-format were analyzed for registration accuracy based on the Hotine Oblique Mercator (HOM) tick marks contained in the annotation record. Independently chosen ground control points were used to evaluate each scene.

The results indicate that 8 out of the 12 showed either good or fairly good registration and that the registration information provided with the MSS data can be used as a starting point from which to make a more precise registration.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

AN EVALUATION OF MSS P-FORMAT DATA REGISTRATION

Summary

The purpose of this study was to determine the relative accuracy of the registration of P-format multispectral scanner (MSS) data using independently chosen ground control points.

The study indicated that it will usually be necessary to improve the local registration of P-format MSS data to meet the accuracy requirements of the scene-to-map task of the AgRISTARS Domestic Crops and Land Cover (DCLC) project. However, it is probable that any other Landsat full-scene (2983 rows by 3548 columns) registration technique also sacrifices accuracies at some local areas. In addition, various sensor or satellite difficulties such as the line start problem (ref. 1) or the light source problem (ref. 2) can degrade the accuracy of the P-format registration information. Nevertheless, the registration information provided with MSS data that have been corrected using ground control points in the Master Data Processor can be used as a starting point from which to make a more precise registration. The algorithm that handles the improved registration can indicate when problems in MSS data registration are likely to have occurred.

Introduction

This report documents an evaluation of the registration accuracy of P-format MSS data, which is the first phase of the scene-to-map registration task of the AgRISTARS DCLC project. (A later phase of the task will deal with the problem of automatically registering USDA segment data with Landsat MSS data.)

The Landsat Users Handbook (ref. 3) describes accuracies associated with data generated by the Master Data Processor (MDP) at the Goddard Space Flight Center. According to the handbook, the accuracy of the ground control points used by the MDP depends on the quality of the reference map from which the points were chosen. When a Landsat scene is automatically registered by the MDP, the registration depends on other variables as well, such as the quality of the data.

The EROS Data Center conducted a geometric accuracy evaluation on two 1979 Landsat images and reported a standard error of about 160m in each of two dimensions (ref. 4). The two images had been system-corrected; that is, corrected without the use of ground control points.

Colwell, Davis, and Thomson (ref. 5) conducted an accuracy evaluation of a July 18, 1979, Landsat scene (30500-15352) that included an area around Toledo, Ohio. The scene had been ground-control corrected. When compared with ground control points from 1:24,000-scale topographic maps, Colwell, et al., reported root mean square (rms) errors of 218.0m in the east-west direction and 879.8m in the north-south direction.

To evaluate the registration accuracy of Landsat MSS data, the analyst must be familiar with and be able to retrieve information in annotation records of computer-compatible tapes (CCT's) produced after February 1979 at the EROS Data Center. The pertinent registration information is given in terms of Hotine Oblique Mercator (HOM) coordinates and Landsat coordinates. These coordinates are often referred to as tick marks and are indicated on the Landsat image photographs provided by the EROS Data Center as U's and V's, the axes names for the HOM projection (ref. 6). The tick marks appear on the top, bottom, right, and left sides of the data and the number of ticks per side vary from scene-to-scene, depending on where the frame center falls with respect to the HOM projection.

The top edge tick marks always intersect with extended Landsat row number -17.5; likewise, the left side ticks always intersect with extended Landsat column -17.5, the right side ticks with extended Landsat column 3565.5, and the bottom edge ticks with extended Landsat row 3000.5. The V and U coordinate values given in the annotation record should be multiplied by 10,000m to obtain the actual coordinate values. Examples of the tick mark information are given in table 1 under the heading "Tick Marks."

The conversions between the tick mark information and the Landsat coordinates and between the Landsat coordinates and other map projections are not straightforward. For this reason, the EROS Data Center made available to the Landsat users software that can be used to convert from one coordinate system (Landsat, UTM, HOM, latitude and longitude) to another (ref. 6). This software was obtained from the EROS Data Center and used for this evaluation.

Also contained in the annotation record of the CCT is an indicator of the type of correction applied and a quality assessment number for the geometric corrections. The indicator can be one of four letters: U for uncorrected, S for system corrected, G for corrected based on ground control points, and R for corrected based on relative ground control points.

The quality assessment number is an integer value that usually ranges from 0 to 5 and indicates, within a range, the number of ground control points used for the geometric correction. The assessment number is the truncated integer of the expression (N+7)/8, where N is the number of control points used. Table 2 shows a breakout of the number of control points associated with assessment numbers 0-5.

The purpose of this study was to evaluate the accuracy of the tick mark registration by using independently chosen ground control points and to answer the following questions:

1. Is the registration accuracy of the MSS data adequate for the scene-to-map registration task of the AgRISTARS DCLC project?

2. Does the registration accuracy depend heavily upon the quality assessment number?

3. What problems are associated with using the registration information on the CCT's and can these problems be "worked around" for the scene-to-map task of the AgRISTARS DCLC project?

Procedure

The procedure used for selecting the independent control points and evaluating the accuracies of these points is outlined in the following steps:

Step 1

Twelve Landsat scenes were used to do the analysis (table 1). The distribution of the 12 scenes within the U.S., shown in figure 1, was mainly dependent on data readily available to the USDA Economics and Statistics Service (ESS) and the Earth Resources Laboratory (ERL) from associated research efforts.

Step 2

Sets of 25 to 38 ground control points were chosen from each scene (tables 3-14). Each control point consisted of four coordinates--latitude, longitude, Landsat row, and Landsat column. Sets 1-6 were chosen by ESS and sets 7-12 were chosen by ERL.

The selection of a control point requires that the analyst be able to find the same feature on a map and in the Landsat imagery; and, after the control point is selected, the analyst must be able to accurately determine the coordinates of the point. Therefore, this process hinges on the Landsat image and the accuracy of the map used. Depending on the type of terrain (mountains, deserts, agriculture fields, etc.), control points can sometimes be difficult to locate. However, control point selection from Landsat imagery is a process that has been used many times over the last 6 to 7 years and hence the technique has been repeatedly improved. Also, because it has been used so much, there are data to document the accuracy of using this method.

To ensure accurate control point selection, the analysts used large-scale maps, usually the USGS 1:24,000-scale, 7-1/2-minute quadrangle sheets, when these were available for the area. For small portions of a few scenes where these sheets were not available, USGS 1:62,500 or 1:250,000 quadrangle sheets were used.

The control points chosen were distributed throughout the scene. In some cases, clouds or terrain features hindered the most desirable distribution. Figures 2-13 show the relative distributions of the control points based on their Landsat coordinates.

Also, to ensure accuracy, the control points as a set were analyzed against a polynomial model. For this study, ESS used a cubic polynomial model and ERL used a linear polynomial model. Both models have been used over the past several years and have produced good results. These models indicated to the analysts which control points yielded large residual errors. The analyst then tried to determine why the point had a large residual. For example, were the coordinates misread either from the map or the Landsat image? Was the point a bend in a river or a winding road where the map coordinates may be less accurate? In any case, when the analyst was satisfied that the coordinates of the point were inaccurate, the coordinates were corrected if possible or the point deleted. If the point coordinates appeared to be accurate and the point had a large residual error, the point was kept.

Historically, this method of control point selection and analysis will produce a registration accuracy of ± 1 Landsat pixel for at least 68 percent of the points for the area being registered.

Step 3

All of the control points chosen at ESS were forwarded to ERL, where all sets were entered into the computer for analysis. Software obtained from the EROS Data Center (Subroutine PIXGEO) was used to compute the Landsat row and column for each latitude and longitude. Inputs to this program include the HOM tick marks, the path and row numbers, the sensor type, the projection type, the Worldwide Reference System longitude, and the type of conversion desired. For the purposes of this study the sensor type was always "MSS", the projection type "H" for Hotine, the Worldwide Reference System longitude 0 (zero), because this value was not used by the program, and the type of conversion was always from latitude and longitude to Landsat coordinates. Therefore, the only inputs that changed for each set of control points were the tick marks, the path and row numbers, and the latitude and longitude of the control points.

The EROS software (Subroutine PIXGEO) used to convert latitude and longitude coordinates to Landsat row and column basically uses two steps. The first step is a conversion from latitude and longitude to the HOM U and V coordinates. The equations that relate the two systems are closed formulas; that is, mathematically there are no approximations or iterations involved. The second step relates the U and V coordinates to the Landsat row and column. This is done by using interpolation among the tick marks given in the annotation record.

Hence, results from both of these steps can be achieved with the accuracy depending almost entirely on the accuracy of the machine. Therefore, if it is assumed that the HOM tick marks are exact (although they are expressed only to the nearest whole row or column number), the error in the conversions from latitude and longitude to Landsat row and column would be much less than $\pm 1/2$ Landsat pixel.

Step 4

The Landsat row and column numbers computed using the EROS software were compared with their corresponding Landsat row and column numbers that were chosen manually. Statistical measures used for the evaluation were determined by the following equations. The row bias was given by:

$$\text{RBIAS} = \frac{\sum_{i=1}^{NP} (\text{ROW1}_i - \text{ROW2}_i)}{NP} ,$$

where NP was the number of ground control points chosen, ROW1 was the Landsat row determined using the EROS software, and ROW2 was the Landsat row read from the Landsat imagery. The row standard deviation was given by:

$$\text{RSD} = \sqrt{\frac{\sum_{i=1}^{NP} (\text{ROW1}_i - \text{ROW2}_i - \text{RBIAS})^2}{NP - 1}}$$

Analogous equations were used for the Landsat column analysis.

Results

The results of applying the statistical measures given in Step 4 above to the data sets are shown in tables 3-14, with a summary given in table 15.

To evaluate the accuracy of each set one has to consider both the RBIAS and the RSD (or the CBIAS and the CSD) at the same time. If only the RBIAS (CBIAS) is small, the row (column) differences could still be large in absolute value but cancel each other because of opposite signs. But, if both the RBIAS (CBIAS) and the standard deviation RSD (CSD) are relatively small, then the registration accuracy is judged to be good. Such was the case with data sets 1, 2, 3, 7, 8, and 9. For these data sets, the RBIAS, RSD, CBIAS, and CSD values were small enough so that one could argue that significant portions of these measures could be attributed to the selection of the independent control points. For example, point No. 1 in data set 8 (table 10) has relatively large values for the row and column differences (ROW1-ROW2, COL1-COL2) when compared with the other control points of set 8. This suggests that point No. 1 was not a good control point. Such errors can increase the standard deviation measure substantially.

The registration of data set 11 was fairly good but showed a consistent error in the Landsat row direction, with an RBIAS of 2.1 and a standard deviation of 1.5.

The RBIAS (−3.6) and the CBIAS (3.2) of data set 10 are significantly higher than those of data sets 1, 2, 3, 7, 8, 9, and 11. The data of this set were somewhat hazy and this, coupled with the terrain of the area, hindered good control point selection. However, the row and column differences seem to be consistent and not random, which may indicate that there was a registration problem associated with the tick marks.

Data set 4 had a consistent bias of approximately 16 Landsat rows. This data set was affected by the scan line-start problem described in reference 1 and approximately the first 30 percent of the data on the left side of the scene could not be used (figure 5). As a result of this problem, the registration accuracy of the scene may have been affected when it was processed through the Master Data Processor. The independently chosen control points used for data set 4 produced a good registration when compared with ground truth information digitized from maps. Therefore, it was concluded that the tick mark registration information of the CCT was inaccurate and not the independently chosen control points. The scene had a quality assessment number of 2, which indicates that 9 to 16 control points were used to register the image.

Data set 12, with a quality assessment number of 4, had a consistent shift in both the Landsat row and column direction of approximately 10 and 9, respectively.

Data sets 5 and 6 showed very poor registration accuracy when compared with the independently chosen ground control points. The major errors were in the north-to-south direction and show consistent biases of approximately −415 Landsat rows and −407 Landsat rows for data sets 5 and 6, respectively. As in the case of data set 4, the independently chosen control points were used to register the scene and, when compared with ground truth information, the registration was quite accurate.

Therefore, it was concluded that the tick mark registration of the CCT's was very inaccurate.

Data set 6 was the only scene of the 12 analyzed that had an assessment number of 0. This means that the scene was system-corrected or corrected without the use of ground control points in the MDP. The quoted accuracy for system-corrected scenes is approximately 2.5 km (ref. 3) or 2.7 km (see the appendix). However, the consistent shift of 407 Landsat rows times approximately 57m per row yields a shift of well over 20 km.

Data set 5 had a quality assessment number of 1, which indicates that 1-8 control points were used to register the scene. However, it seems to be slightly less accurate than scene 6, which had an assessment number of 0.

In an attempt to relate the registration inaccuracies of the CCT's to problems experienced by the sensor system or the MDP, the results of this study were compared with known, documented problems.

During the period from June 14, 1979, to August 1, 1979, a patch in the MDP caused the utilization of ground control points to be bypassed. However, this was not properly indicated in the header or the annotation records (see appendix). Therefore, some high-density tapes generated during this time may not have been corrected with control points, although the quality assessment number may be greater than 0.

Of the 12 data sets evaluated, only two were generated during the period in which the patch was used. These were data sets 1 and 2, whose registration was good. The high density P-tape numbers of data set 1 (L2MHP79204-08) and data set 2 (L2MHP79210-05) were not on the list given in the appendix. Therefore, it was assumed that none of the 12 data sets of this study were affected by the patch in the MDP.

As reported in reference 2, a switch from light source A to light source B in the Landsat 3 MSS sensor system caused a shift in the ground representation of the scan lines of approximately 2,052 to 2,166 meters (36 to 38 pixels).

The light source on Landsat 3 has been switched back and forth between source A and source B several times. Landsat 2 was launched with light source A, switched to source B on August 24, 1979, and has remained there.

The light source switching is a potential problem for scenes being corrected using the ground control points of the MDP. However, the shift occurs in the scan-line (west-to-east) direction and none of the 12 scenes analyzed in this study showed an error of such magnitude in the west-to-east (COL1-COL2) direction.

The scan line start problem (ref. 1) affected only one of the 12 scenes analyzed in this study. As stated earlier, this problem seems to have degraded the registration accuracy in the north-to-south direction.

Conclusions

The conclusions are stated as answers to the three questions asked in the introduction.

1. Is the registration accuracy of the MSS data adequate for the scene-to-map registration task of the AgRISTARS DCLC project?

No, because the scene-to-map registration task requires an error of less than a pixel for each ESS segment within the scene. Therefore, a more precise local fitting will be required for each segment. However, the registration of the P-format Landsat MSS data that have been registered using the control points in the MDP can be used as a starting point for an algorithm that will automatically register the ESS segment data to the Landsat MSS data. If the algorithm uses a search window of 10 Landsat columns by 10 Landsat rows, then out of the 12 Landsat scenes analyzed in this study, 8 would fall within the window search area of this algorithm.

2. Does the registration accuracy depend heavily upon the quality assessment number?

The quality assessment number is not necessarily a good indicator of the registration accuracy. For example, data sets 4, 10, and 12 had higher assessment numbers than data set 3 but showed poorer registration accuracy for this evaluation. Figure 14 shows a plot of the quality assessment number versus the relative errors of registration for the 12 data sets. This plot shows that the relative error does not necessarily decrease as the quality assessment number increases.

3. What problems are associated with using the registration information on the CCT's and can these problems be "worked around" for the scene-to-map task of the AgRISTARS DCLC project?

The potential documented problems of bypassed control points in the MDP, the scan line start problem, and the light source switch were enumerated earlier. When there are problems with the registration defined by the tick marks, such as in the cases of data sets 4, 5, 6, and 12, the algorithm would compute low correlations for all attempts to match the segment data with the Landsat data within the 10 x 10 window. This would be an indication to the analyst that there is a problem with the data set and that the data set will have to be registered by another technique.

TABLE 1. CATALOG OF DATA SETS 1-12

DATA SET NUMBER	SCENE ID	STATE	PATH/ROW	DATE GEN. BY MDP	ASSESS. NUMBER	TICK MARKS							
						TOP		BOTTOM		RIGHT		LEFT	
						V	COL	V	COL	U	ROW	U	ROW
1	21629-17145	AZ	39/37	7/23/79	5	40	151	45	872	475	81	470	772
						45	1030	50	1751	470	959	465	1651
						50	1908	55	2629	465	1838	460	2529
						55	2787	60	3507	460	2716		
2	21646-17092	AZ	38/37	7/29/79	4	40	95	45	816	475	84	470	775
						45	973	50	1694	470	962	465	1654
						50	1852	55	2573	465	1841	460	2532
						55	2730	60	3451	460	2719		
3	21676-16321	SD	32/39	8/30/79	1	40	59	45	752	605	235	605	15
						45	938	50	1631	600	1114	600	894
						50	1816	55	2509	595	1993	595	1772
						55	2695	60	3388	590	2872	590	2651
4	30777-16104	MO KS	28/34	4/23/80	2	40	49	45	761	520	805	520	607
						45	928	50	1639	515	1684	515	1485
						50	1806	55	2518	510	2562	510	2364
						55	2685	60	3396				
5	21961-16204	KS	29/34	5/18/80	1	45	738	45	571	520	816	520	617
						50	1617	50	1450	515	1694	515	1496
						55	2495	55	2328	510	2573	510	2374
						60	3374	60	3207				
6	21961-16202	KS	29/33	5/18/80	0	45	752	45	581	540	159	535	835
						50	1630	50	1460	535	1037	530	1713
						55	2509	55	2338	530	1916	525	2592
						60	3388	60	3217	525	2794		
7	21564-16075	MO	28/33	5/12/79	3	40	14	45	722	540	149	535	825
						45	892	50	1600	535	1028	530	1704
						50	1771	55	2479	530	1906	525	2583
						55	2649	60	3357	525	2785		
						60	3528						

TABLE 1. CATALOG OF DATA SETS 1-12 (continued)

DATA SET NUMBER	SCENE ID	STATE	PATH/ROW	DATE GEN. BY MDP	ASSESS. NUMBER	TICK MARKS TOP V	TOP COL	BOTTOM V	BOTTOM COL	RIGHT U	RIGHT ROW	LEFT U	LEFT ROW
8	30435-16171	MO	28/33	6/4/79	2	40	248	40	77	540	136	535	812
						45	1126	45	956	535	1015	530	1691
						50	2005	50	1834	530	1893	525	2569
						55	2883	55	2713	525	2772		
9	30556-15474	KY	23/24	9/15/80	2	40	318	40	151	520	788	520	589
						45	1197	45	1030	515	1666	515	1468
						50	2075	50	1908	510	2545	510	2346
						55	2954	55	2787				
10	30623-15181	SC	18/36	2/15/80	3	40	120	45	838	490	328	490	138
						45	998	50	1716	485	1207	485	1016
						50	1877	55	2594	480	2085	480	1895
						55	2755	60	3473	475	2964	475	2773
11	21654-16100	MO	28/32	8/5/79	2	40	40	45	744	555	411	555	204
						45	919	50	1623	550	1290	550	1082
						50	1797	55	2501	545	2168	545	1961
						55	2676	60	3380			540	2840
12	21980-16270	KS	30/34	5/28/80	4	40	37	45	749	520	806	520	608
						45	916	50	1627	515	1685	515	1486
						50	1795	55	2506	510	2563	510	2365
						55	2673	60	3384				

TABLE 2. ASSESSMENT NUMBERS (0-5) VS. NUMBER OF CONTROL POINTS

ASSESSMENT NUMBER	NUMBER OF CONTROL POINTS USED BY MDP
0	0
1	1- 8
2	9-16
3	17-24
4	25-32
5	33-40

TABLE 3. INDEPENDENTLY CHOSEN CONTROL POINTS (LATITUDE, LONGITUDE, ROW2, COL2) COMPARED WITH LANDSAT COORDINATES (ROW1, COL1) DETERMINED FROM P-FORMAT REGISTRATION FOR DATA SET 1

	LATITUDE	LONGITUDE	ROW1	ROW2	ROW1-ROW2	COL1	COL2	COL1-COL2
1	33.68224	-112.3938	543.7	544.5	-0.8	397.4	398.9	-1.5
2	33.21674	-112.4265	1444.3	1442.0	2.3	508.8	509.5	-0.7
3	33.43587	-112.3752	1009.7	1010.7	-1.0	514.0	515.5	-1.5
4	33.07320	-112.0311	1600.7	1600.4	0.3	1196.3	1198.8	-2.5
5	32.92781	-112.1340	1909.8	1908.9	0.9	1082.5	1083.1	-0.6
6	32.63733	-112.2030	2486.2	2487.0	-0.8	1074.5	1075.4	-0.9
7	32.51114	-112.8239	2912.0	2913.5	-1.5	112.6	113.5	-0.9
8	33.65125	-111.8900	452.7	451.4	1.3	1214.5	1214.4	0.1
9	33.66678	-111.4733	295.7	296.8	-1.1	1875.0	1875.7	-0.7
10	33.67168	-111.1606	189.2	190.5	-1.3	2372.8	2372.5	0.3
11	33.44971	-110.8339	509.5	507.0	2.5	2978.9	2974.8	4.1
12	33.45116	-111.5628	735.3	735.2	0.1	1811.2	1811.6	-0.4
13	33.30510	-111.9797	1141.7	1140.9	0.8	1195.6	1195.8	-0.2
14	33.03835	-111.3611	1461.4	1460.3	1.1	2287.5	2287.2	0.3
15	32.97791	-110.7789	1392.1	1390.5	1.6	3246.8	3248.5	-1.7
16	32.96735	-111.7237	1709.4	1708.5	0.9	1729.7	1730.4	-0.7
17	32.76299	-111.7739	2115.4	2114.4	1.0	1723.1	1723.3	-0.[illegible]
18	32.71953	-111.4468	2097.1	2097.2	-0.1	2267.3	2267.8	-0.5
19	32.66283	-111.0500	2080.2	2078.0	2.2	2929.2	2930.0	-0.8
20	32.49704	-111.4986	2538.3	2537.9	0.4	2265.6	2265.8	-0.2
21	32.46094	-111.8656	2721.0	2720.3	0.7	1683.9	1684.4	-0.5
22	32.38077	-111.1692	2656.5	2656.2	0.3	2842.2	2842.0	0.2
23	32.76772	-111.9629	2164.2	2163.4	0.8	1416.1	1416.1	-0.0
24	32.57699	-111.6722	2435.7	2434.4	1.3	1954.5	1954.4	0.1
25	32.46857	-112.2679	2828.6	2828.8	-0.2	1029.3	1026.8	2.5
				RBIAS=	0.5		CBIAS=	-0.3
				RSD=	1.1		CSD=	1.3

TABLE 4. INDEPENDENTLY CHOSEN CONTROL POINTS (LATITUDE, LONGITUDE, ROW2, COL2) COMPARED WITH LANDSAT COORDINATES (ROW1, COL1) DETERMINED FROM P-FORMAT REGISTRATION FOR DATA SET 2

	LATITUDE	LONGITUDE	ROW1	ROW2	ROW1-ROW2	COL1	COL2	COL1-COL2
1	33.64954	-111.0303	627.1	629.0	-1.9	239.5	239.0	0.5
2	33.17393	-111.0069	1530.6	1530.0	0.6	444.2	442.0	2.2
3	32.97430	-111.1390	1951.7	1951.5	0.2	301.3	300.0	1.3
4	32.59918	-111.3278	2725.4	2727.0	-1.6	126.4	125.0	1.4
5	32.67194	-110.8907	2456.7	2456.5	0.2	808.8	808.0	0.8
6	32.98903	-110.7865	1818.8	1816.0	2.8	864.6	863.0	1.6
7	33.17493	-110.5279	1385.4	1383.5	1.9	1214.4	1215.0	-0.6
8	33.38060	-110.3890	950.0	949.0	1.0	1363.1	1362.0	1.1
9	33.77681	-110.4998	225.9	228.0	-2.1	1042.4	1042.0	0.4
10	33.74226	-110.0569	157.1	159.0	-1.9	1762.1	1762.0	0.1
11	33.32758	-110.0383	943.6	943.5	0.1	1944.9	1944.0	0.9
12	32.82022	-110.3147	1998.4	1997.0	1.4	1686.3	1686.0	0.3
13	32.60008	-110.6952	2535.3	2535.0	0.3	1150.8	1150.0	0.8
14	32.52791	-110.5946	2642.8	2643.0	-0.2	1339.6	1340.0	-0.4
15	32.42763	-109.9603	2638.3	2635.5	2.8	2403.6	2404.5	-0.9
16	32.91168	-109.8515	1679.7	1681.0	-1.3	2399.4	2401.0	-1.6
17	32.81639	-109.6470	1797.0	1794.5	2.5	2764.6	2765.5	-0.9
18	32.32935	-109.4924	2677.2	2669.5	7.7	3198.4	3200.0	-1.6
19	32.60693	-109.9456	2291.2	2287.0	4.2	2360.9	2363.0	-2.1
20	33.30055	-109.7130	893.6	893.5	0.1	2476.6	2477.0	-0.4
21	33.35980	-109.6730	767.9	768.0	-0.1	2518.4	2519.0	-0.6
22	33.63100	-109.6875	254.7	256.0	-1.3	2393.3	2393.0	0.3
23	33.49760	-109.2114	357.8	359.0	-1.2	3204.6	3204.0	0.6
24	33.02582	-109.3270	1295.1	1292.0	3.1	3200.2	3200.0	0.2
25	32.59363	-109.5234	2182.8	2178.0	4.8	3048.2	3050.0	-1.8
				RBIAS=	0.9		CBIAS=	0.1
				RSD=	2.4		CSD=	1.1

TABLE 5. INDEPENDENTLY CHOSEN CONTROL POINTS (LATITUDE, LONGITUDE, ROW2, COL2) COMPARED WITH LANDSAT COORDINATES (ROW1, COL1) DETERMINED FROM P-FORMAT REGISTRATION FOR DATA SET 3

	LATITUDE	LONGITUDE	ROW1	ROW2	ROW1-ROW2	COL1	COL2	COL1-COL2
1	44.82158	-98.2983	961.0	960.0	1.0	746.4	746.0	0.4
2	44.77147	-98.5099	1118.8	1117.0	1.8	480.3	480.0	0.3
3	44.70621	-98.2771	1174.4	1173.0	1.4	823.3	823.0	0.3
4	44.60268	-98.2558	1365.2	1365.0	0.2	895.5	894.0	1.5
5	44.41792	-98.1510	1685.4	1686.0	-0.6	1115.7	1116.0	-0.3
6	44.36411	-98.1986	1802.2	1803.0	-0.8	1073.3	1073.0	0.3
7	45.18381	-97.9238	159.6	158.0	1.6	1099.6	1098.0	1.6
8	45.12170	-97.5478	163.2	162.0	1.2	1632.1	1633.0	-0.9
9	44.48152	-97.6172	1401.4	1402.0	-0.6	1815.8	1816.0	-0.2
10	44.33568	-97.5059	1643.9	1645.0	-1.1	2030.7	2031.0	-0.3
11	44.18654	-97.6953	1986.4	1988.0	-1.6	1836.7	1835.0	1.7
12	43.98820	-97.1640	2195.8	2197.0	-1.2	2650.6	2651.0	-0.4
13	43.98082	-97.0818	2183.5	2185.0	-1.5	2766.6	2768.0	-1.4
14	44.26482	-97.0594	1637.3	1638.0	-0.7	2670.7	2672.0	-1.3
15	44.43990	-96.9836	1280.7	1281.0	-0.3	2695.7	2696.0	-0.3
16	44.56120	-97.1457	1102.2	1102.0	0.2	2421.6	2421.0	0.[illegible]
17	44.65729	-97.0413	886.6	887.0	-0.4	2520.3	2520.0	0.[illegible]
18	44.66486	-97.2165	927.8	926.0	1.8	2279.7	2280.0	-0.3
19	44.77676	-97.1531	695.3	694.0	1.3	2316.0	2316.0	-0.0
20	44.85367	-97.2147	568.7	566.0	2.7	2198.6	2199.0	-0.4
21	44.95644	-97.1992	364.9	363.0	1.9	2173.2	2175.0	-1.8
22	45.01068	-97.3471	312.0	310.5	1.5	1950.9	1951.0	-0.1
23	44.96672	-96.8475	237.5	239.0	-1.5	2643.4	2646.0	-2.6
24	44.74170	-96.6616	604.4	604.0	0.4	2995.9	2997.0	-1.1
25	44.53087	-96.5399	964.4	965.0	-0.6	3256.8	3256.0	0.8
26	44.19083	-96.8562	1712.2	1713.0	-0.8	2981.1	2982.0	-0.9
				RBIAS=	0.2		CBIAS=	-0.2
				RSD=	1.3		CSD=	1.0

TABLE 6. INDEPENDENTLY CHOSEN CONTROL POINTS (LATITUDE, LONGITUDE, ROW2, COL2) COMPARED WITH LANDSAT COORDINATES (ROW1, COL1) DETERMINED FROM P-FORMAT REGISTRATION FOR DATA SET 4

	LATITUDE	LONGITUDE	ROW1	ROW2	ROW1-ROW2	COL1	COL2	COL1-COL2
1	38.08823	-94.5716	101.2	87.5	13.7	1391.0	1391.5	-0.5
2	37.96461	-94.7131	380.2	366.5	13.7	1224.6	1226.0	-1.4
3	37.81142	-94.7806	693.1	679.0	14.1	1181.0	1181.0	-0.0
4	37.76143	-94.7592	782.1	769.5	12.6	1232.5	1233.5	-1.0
5	37.52834	-94.8333	1249.6	1236.5	13.1	1208.7	1209.0	-0.3
6	37.61592	-94.8505	1087.6	1074.5	13.1	1149.3	1150.5	-1.2
7	37.28174	-94.9404	1752.9	1741.0	11.9	1139.1	1139.5	-0.4
8	37.08978	-94.9950	2136.1	2123.5	12.6	1128.0	1128.5	-0.5
9	37.02365	-94.7128	2176.5	2163.0	13.5	1584.9	1584.0	0.9
10	37.17799	-94.7953	1907.0	1893.5	13.5	1400.0	1399.7	0.3
11	37.39638	-94.7047	1462.5	1449.0	13.5	1454.9	1454.5	0.4
12	37.67322	-94.7032	933.5	919.0	14.5	1351.2	1350.0	1.2
13	37.75116	-94.5839	748.4	734.0	14.4	1502.2	1501.5	0.7
14	37.21715	-94.5782	1765.8	1749.0	16.8	1716.5	1716.5	-0.0
15	37.01247	-94.5691	2153.6	2139.0	14.6	1809.2	1806.5	2.7
16	37.83826	-94.4191	531.5	516.5	15.0	1718.1	1718.5	-0.4
17	37.86319	-94.6402	551.7	537.5	14.2	1373.9	1374.0	-0.1
18	37.52783	-94.6673	1200.1	1186.0	14.1	1461.3	1461.0	0.3
19	37.19330	-94.9041	1910.9	1898.0	12.9	1227.9	1225.5	2.4
20	37.19867	-94.6373	1819.2	1805.0	14.2	1633.4	1633.5	-0.1
21	37.06046	-94.8313	2142.4	2129.0	13.4	1389.7	1389.5	0.2
22	37.96883	-94.1526	199.9	184.0	15.9	2070.0	2070.0	-0.0
23	37.32437	-94.2847	1470.1	1452.5	17.6	2122.5	2123.0	-0.5
24	37.66187	-94.3101	834.3	817.5	16.8	1951.9	1953.0	-1.1
25	37.47128	-94.5726	1279.1	1265.0	14.1	1627.1	1626.0	1.1
26	36.67043	-94.9810	2932.8	2921.0	11.8	1307.5	1305.5	2.0
27	36.79939	-94.7527	2616.8	2602.0	14.8	1609.5	1606.0	3.5
28	36.92557	-94.7397	2372.0	2358.0	14.0	1581.2	1577.5	3.7
29	36.67221	-93.9415	2604.9	2577.5	27.4	2904.2	2900.0	4.2
30	37.08585	-93.8508	1787.6	1767.0	20.6	2878.3	2880.5	-2.2
31	37.34261	-93.7763	1274.5	1252.5	22.0	2889.2	2890.5	-1.3
32	37.69994	-93.7567	587.5	566.5	21.0	2775.4	2774.0	1.4
33	37.88759	-93.7828	238.2	219.0	19.2	2660.6	2661.0	-0.4
34	37.04520	-93.5734	1775.5	1750.5	25.0	3318.2	3317.5	0.7
35	37.56709	-93.3946	723.6	700.0	23.6	3377.8	3372.5	5.3
				RBIAS=	15.8		CBIAS=	0.6
				RSD=	3.9		CSD=	1.7

TABLE 7. INDEPENDENTLY CHOSEN CONTROL POINTS (LATITUDE, LONGITUDE, ROW2, COL2) COMPARED WITH LANDSAT COORDINATES (ROW1, COL[illegible] DETERMINED FROM P-FORMAT REGISTRATION FOR DATA SET 5

	LATITUDE	LONGITUDE	ROW1	ROW2	ROW1-ROW2	COL1	COL2	COL1-COL2
1	37.93796	-96.4673	526.9	951.0	-424.1	561.1	553.0	8.1
2	38.03966	-96.6188	377.3	803.0	-425.7	293.8	285.0	8.8
3	37.03142	-96.9342	2397.6	2825.0	-427.4	186.4	178.0	8.4
4	37.21732	-96.3045	1854.6	2275.0	-420.4	1080.7	1071.0	9.7
5	37.68198	-96.1115	908.7	1328.0	-419.3	1197.6	1188.0	9.6
6	37.76845	-95.9085	681.7	1100.0	-418.3	1472.0	1463.0	9.0
7	37.80710	-95.8498	589.9	1010.0	-420.1	1545.9	1538.0	7.9
8	37.99631	-95.5479	135.4	552.0	-416.6	1928.2	1919.0	9.2
9	37.96590	-95.4748	170.5	587.0	-416.5	2050.5	2042.0	8.5
10	37.91489	-95.3979	243.6	659.0	-415.4	2187.0	2178.0	9.0
11	37.84892	-95.4716	392.5	809.0	-416.5	2101.8	2093.0	8.8
12	37.80307	-95.4502	473.2	889.0	-415.8	2152.4	2143.0	9.4
13	37.71930	-95.4555	634.6	1050.0	-415.4	2177.6	2169.0	8.6
14	37.67392	-95.4121	707.4	1121.0	-413.6	2261.3	2252.0	9.3
15	37.69899	-95.6688	740.1	1157.0	-416.9	1862.4	1853.0	9.4
16	37.59610	-95.3251	828.2	1242.0	-413.8	2424.2	2415.0	9.2
17	37.26028	-95.8470	1632.3	2049.0	-416.7	1762.6	1752.0	10.[illegible]
18	36.94922	-96.1761	2327.4	2745.0	-417.6	1379.3	1368.0	11[illegible]
19	36.87006	-94.9279	2083.5	2490.0	-406.5	3322.0	3311.0	11.[illegible]
20	36.93634	-94.9568	1966.7	2374.0	-407.3	3250.8	3240.0	10.8
21	36.97644	-95.0373	1916.5	2324.0	-407.5	3111.4	3102.0	9.4
22	37.04860	-95.0817	1793.4	2202.0	-408.6	3014.5	3005.0	9.5
23	37.19911	-95.1012	1513.0	1923.0	-410.0	2923.9	2915.0	8.9
24	37.26564	-95.1136	1390.3	1801.0	-410.7	2878.2	2870.0	8.2
25	37.35880	-95.1174	1214.1	1624.0	-409.9	2834.8	2826.0	8.8
26	37.41663	-95.1403	1111.2	1522.0	-410.8	2776.8	2768.0	8.8
27	37.49754	-95.1668	965.6	1377.0	-411.4	2703.8	2693.0	10.8
28	37.54060	-95.2294	903.6	1316.0	-412.4	2591.5	2582.0	9.5
29	37.79720	-95.0650	362.1	775.0	-412.9	2737.2	2729.0	8.2
30	37.75964	-94.8527	364.8	777.0	-412.2	3073.3	3065.0	8.3
31	37.64285	-94.8065	572.5	982.0	-409.5	3191.1	3183.0	8.1
				RBIAS=	-414.8		CBIAS=	9.2
				RSD=	5.3		CSD=	0.9

TABLE 8. INDEPENDENTLY CHOSEN CONTROL POINTS (LATITUDE, LONGITUDE, ROW2, COL2) COMPARED WITH LANDSAT COORDINATES (ROW1, COL1) DETERMINED FROM P-FORMAT REGISTRATION FOR DATA SET 6

	LATITUDE	LONGITUDE	ROW1	ROW2	ROW1-ROW2	COL1	COL2	COL1-COL2
1	39.48769	-95.6876	180.2	592.0	-411.8	989.2	979.0	10.2
2	39.20299	-96.2226	883.2	1297.0	-413.8	305.1	298.0	7.1
3	39.09311	-95.6294	915.3	1325.0	-409.7	1229.4	1219.0	10.4
4	38.99054	-95.6313	1111.6	1522.0	-410.4	1266.6	1257.0	9.6
5	39.05399	-95.4953	949.0	1358.0	-409.0	1444.2	1435.0	9.2
6	38.80203	-95.6400	1473.8	1883.0	-409.2	1327.2	1318.0	9.2
7	38.64543	-95.5615	1748.5	2158.0	-409.5	1505.8	1496.0	9.8
8	38.31528	-95.9529	2497.9	2913.0	-415.1	1046.7	1036.0	10.7
9	38.66693	-96.1565	1887.6	2303.0	-415.4	606.8	598.0	8.8
10	38.85469	-96.1950	1540.4	1955.0	-414.6	478.0	469.0	9.0
11	38.82851	-95.3911	1346.8	1753.0	-406.2	1688.3	1679.0	9.3
12	38.90257	-95.4207	1214.7	1622.0	-407.3	1614.9	1605.0	9.9
13	38.93721	-95.3456	1125.5	1533.0	-407.5	1713.0	1703.0	10.0
14	39.17093	-95.5245	734.9	1145.0	-410.1	1354.8	1344.0	10.8
15	39.17677	-95.4160	690.5	1097.0	-406.5	1513.5	1504.0	9.5
16	39.47701	-95.0280	-2.1	405.0	-407.1	1968.2	1957.0	11.2
17	39.12614	-95.1432	702.4	1108.0	-405.6	1938.7	1928.0	10.7
18	39.12613	-95.1432	702.5	1108.0	-405.5	1938.7	1928.0	10.7
19	38.11725	-94.8996	2547.1	2945.0	-397.9	2709.7	2699.0	10.7
20	38.26253	-94.7082	2208.9	2613.0	-404.1	2938.1	2929.0	9.1
21	38.27425	-94.8217	2223.2	2627.0	-403.8	2762.9	2755.0	7.9
22	38.41722	-94.7929	1941.7	2346.0	-404.3	2747.9	2739.0	8.9
23	38.85210	-94.9247	1155.7	1560.0	-404.3	2374.2	2365.0	9.2
24	38.87978	-94.8678	1084.9	1489.0	-404.1	2447.7	2439.0	8.7
25	38.98285	-94.9203	905.3	1309.0	-403.7	2327.7	2319.0	8.7
26	39.02370	-94.8699	817.9	1223.0	-405.1	2356.3	2347.0	9.3
27	39.07936	-94.7266	660.0	1062.0	-402.0	2576.1	2568.0	8.1
28	39.09122	-94.6085	599.6	1003.0	-403.4	2746.5	2738.0	8.5
29	39.16727	-94.6606	471.5	878.0	-406.5	2638.0	2629.0	9.0
				RBIAS=	-407.4		CBIAS=	9.5
				RSD=	4.2		CSD=	1.0

TABLE 9. INDEPENDENTLY CHOSEN CONTROL POINTS (LATITUDE, LONGITUDE, ROW2, COL2) COMPARED WITH LANDSAT COORDINATES (ROW1, COL1) DETERMINED FROM P-FORMAT REGISTRATION FOR DATA SET 7

	LATITUDE	LONGITUDE	ROW1	ROW2	ROW1-ROW2	COL1	COL2	COL1-COL2
1	39.63109	-94.7300	45.8	44.0	1.8	370.2	367.0	3.2
2	39.38060	-94.7656	540.9	539.0	1.9	382.8	380.0	2.8
3	39.26389	-94.6156	772.8	773.0	-0.2	382.4	381.0	1.4
4	39.16919	-94.1900	766.7	766.0	0.7	1347.9	1347.0	0.9
5	39.15579	-94.4722	877.5	879.0	-1.5	933.8	935.0	-1.2
6	39.22690	-94.7036	806.7	807.0	-0.3	562.0	561.0	1.0
7	39.10609	-94.8344	1080.0	1080.0	-0.0	414.0	412.0	2.0
8	39.00690	-94.8528	1275.1	1275.0	0.1	424.0	423.0	1.0
9	39.05579	-94.5717	1098.3	1098.0	0.3	824.2	822.0	2.2
10	39.02359	-94.3156	1082.7	1083.0	-0.3	1217.8	1218.0	-0.2
11	39.30170	-93.8417	407.0	406.0	1.0	1812.2	1810.0	2.2
12	39.27609	-93.4072	319.8	319.0	0.8	2465.9	2465.0	0.9
13	39.26139	-93.3611	301.5	299.0	2.5	2502.4	2501.0	1.4
14	39.32919	-93.2297	162.3	160.0	2.3	2706.8	2704.0	2.8
15	39.23499	-93.7583	508.3	507.0	1.3	1962.4	1961.0	1.4
16	38.83330	-94.8675	1617.1	1617.0	0.1	437.6	436.0	1.6
17	38.78169	-94.6489	1645.0	1644.0	1.0	813.7	812.0	1.7
18	38.86359	-94.2381	1364.6	1364.0	0.6	1395.5	1394.0	1.5
19	38.53419	-94.8631	2181.7	2182.0	-0.3	586.7	585.0	1.7
20	38.40329	-94.6872	2379.4	2378.0	1.4	900.4	899.0	1.4
21	38.34499	-94.7708	2515.8	2513.0	2.8	796.9	795.0	1.9
22	38.21609	-94.1572	2575.4	2573.0	2.4	1769.6	1769.0	0.6
23	38.79919	-93.8689	1373.7	1374.0	-0.3	1971.6	1971.0	0.6
24	38.77190	-93.6492	1357.0	1356.0	1.0	2310.3	2309.0	1.3
25	38.71529	-93.1719	1312.6	1313.0	-0.4	3045.1	3044.0	1.1
26	38.69029	-93.4131	1437.6	1438.0	-0.4	2695.5	2695.0	0.5
27	38.25420	-93.3619	2251.8	2253.0	-1.2	2949.7	2946.0	3.7
28	38.22060	-93.7614	2443.2	2442.0	1.2	2363.1	2363.0	0.1
				RBIAS=	0.7		CBIAS=	1.4
				RSD=	1.1		CSD=	1.0

TABLE 10. INDEPENDENTLY CHOSEN CONTROL POINTS (LATITUDE, LONGITUDE, ROW2, COL2) COMPARED WITH LANDSAT COORDINATES (ROW1, COL1) DETERMINED FROM P-FORMAT REGISTRATION FOR DATA SET 8

	LATITUDE	LONGITUDE	ROW1	ROW2	ROW1-ROW2	COL1	COL2	COL1-COL2
1	39.37140	-94.9161	597.0	594.0	3.0	426.5	430.0	-3.5
2	39.16919	-94.1900	766.9	766.0	0.9	1581.7	1583.0	-1.3
3	39.16919	-94.7697	940.5	939.0	1.5	720.2	722.0	-1.8
4	38.76859	-93.5847	1343.1	1343.0	0.1	2641.6	2641.0	0.6
5	39.29390	-93.7219	385.0	384.0	1.0	2226.4	2227.0	-0.6
6	38.77190	-93.6492	1357.1	1357.0	0.1	2544.1	2545.0	-0.9
7	38.23029	-93.3897	2306.4	2306.0	0.4	3152.0	3153.0	-1.0
8	39.27640	-93.4156	322.2	321.0	1.2	2686.9	2688.0	-1.1
9	39.20389	-93.2822	417.9	417.0	0.9	2914.1	2916.0	-1.9
10	39.23499	-93.7583	508.6	506.0	2.6	2196.1	2197.0	-0.9
11	38.54610	-93.2150	1648.8	1647.0	1.8	3284.4	3283.0	1.4
12	39.31279	-92.9575	106.2	104.0	2.2	3349.4	3350.0	-0.6
13	38.77609	-93.7750	1388.6	1387.0	1.6	2354.8	2355.0	-0.2
14	39.31389	-93.3669	235.4	233.0	2.4	2743.7	2744.0	-0.3
15	39.03310	-94.3611	1078.5	1078.0	0.5	1380.2	1381.0	-0.8
16	39.10579	-94.7389	1052.6	1050.0	2.6	790.0	792.0	-2.0
17	39.15579	-94.4722	877.7	879.0	-1.3	1167.6	1171.0	-3.4
18	39.08220	-94.2778	959.6	958.0	1.6	1485.1	1484.0	1.1
19	39.30170	-93.8417	407.3	406.0	1.3	2045.9	2046.0	-0.1
20	39.19719	-93.7233	569.8	568.0	1.8	2263.1	2264.0	-0.9
21	39.17940	-93.7886	624.0	621.0	3.0	2173.4	2172.0	1.4
22	38.48309	-93.2375	1776.0	1775.0	1.0	3276.6	3277.0	-0.4
23	39.33249	-93.3975	209.6	208.0	1.6	2690.9	2692.0	-1.1
24	39.32469	-93.1619	149.4	147.0	2.4	3042.4	3043.0	-0.6
25	38.86359	-94.2381	1364.7	1365.0	-0.3	1629.3	1630.0	-0.7
26	38.69029	-93.4131	1437.8	1438.0	-0.2	2929.4	2930.0	-0.6
				RBIAS=	1.3		CBIAS=	-0.8
				RSD=	1.1		CSD=	1.2

TABLE 11. INDEPENDENTLY CHOSEN CONTROL POINTS (LATITUDE, LONGITUDE, ROW2, COL2) COMPARED WITH LANDSAT COORDINATES (ROW1, COL1) DETERMINED FROM P-FORMAT REGISTRATION FOR DATA SET 9

	LATITUDE	LONGITUDE	ROW1	ROW2	ROW1-ROW2	COL1	COL2	COL1-COL2
1	38.14780	-88.1614	211.5	212.0	-0.5	488.6	491.0	-2.4
2	38.15860	-88.1872	198.3	198.0	0.3	445.7	448.0	-2.3
3	38.05359	-88.1342	383.6	384.0	-0.4	564.6	567.0	-2.4
4	38.04669	-88.1914	413.5	414.0	-0.5	480.6	483.0	-2.4
5	37.96579	-88.1394	553.0	553.0	0.0	589.2	591.0	-1.8
6	37.86389	-88.1736	757.9	758.0	-0.1	575.1	577.0	-1.9
7	37.81329	-88.2817	886.2	886.0	0.2	429.8	431.0	-1.2
8	37.72829	-88.3208	1060.1	1059.0	1.1	401.6	401.0	0.6
9	37.38829	-88.3133	1708.2	1709.0	-0.8	537.7	539.0	-1.3
10	37.45940	-88.3917	1595.0	1594.0	1.0	392.1	392.0	0.1
11	37.14420	-88.4078	2202.6	2200.0	2.6	482.6	485.0	-2.4
12	37.02779	-88.4461	2436.4	2437.0	-0.6	466.4	469.0	-2.6
13	36.84859	-88.4369	2776.5	2777.0	-0.5	545.8	546.0	-0.2
14	38.13190	-87.9428	177.7	177.0	0.7	824.6	827.0	-2.4
15	37.91060	-87.9042	589.2	589.0	0.2	965.9	966.0	-0.1
16	37.84779	-87.9836	732.7	733.0	-0.3	869.1	870.0	-0.9
17	37.71419	-87.9156	967.9	969.0	-1.1	1022.3	1024.0	-1.7
18	37.66579	-87.9914	1082.9	1080.0	2.9	925.2	928.0	-2.8
19	37.33890	-88.0797	1733.8	1732.0	1.8	912.5	913.0	-0.5
20	37.08719	-88.0611	2209.4	2209.0	0.4	1034.5	1035.0	-0.5
21	37.06969	-88.1475	2268.5	2268.0	0.5	908.7	909.0	-0.3
22	36.80629	-88.2017	2788.1	2786.0	2.1	922.9	922.0	0.9
23	36.77029	-88.1306	2835.8	2836.0	-0.2	1045.6	1045.0	0.6
24	36.73279	-88.2461	2941.8	2942.0	-0.2	881.7	881.0	0.7
25	37.83719	-87.3772	570.7	570.0	0.7	1791.8	1792.0	-0.2
26	37.97249	-87.3217	295.5	296.0	-0.5	1823.4	1823.0	0.4
27	37.96779	-86.9064	176.0	176.0	0.0	2452.5	2453.0	-0.5
28	37.83829	-87.0156	457.0	458.0	-1.0	2338.6	2338.0	0.6
29	36.65689	-87.3692	2820.7	2822.0	-1.3	2259.4	2260.0	-0.6
30	36.62469	-87.3175	2866.1	2867.0	-0.9	2351.3	2351.0	0.3
31	36.68309	-87.4414	2793.1	2793.0	0.1	2138.3	2139.0	-0.7
32	36.66919	-87.4958	2836.4	2835.0	1.4	2060.0	2060.0	-0.0
33	36.66750	-87.5686	2862.1	2862.0	0.1	1948.6	1949.0	-0.4
34	37.90169	-86.7458	251.6	250.0	1.6	2721.3	2721.0	0.3
35	37.28249	-86.7433	1431.0	1430.0	1.0	2972.0	2972.0	-0.0
36	36.53360	-86.8819	2902.6	2900.0	2.6	3057.1	3058.0	-0.9
37	36.66750	-86.8522	2637.9	2637.0	0.9	3049.8	3049.0	0.8
38	37.44469	-88.3169	1601.4	1602.0	-0.6	511.5	514.0	-2.5
				RBIAS=	0.3		CBIAS=	-0.8
				RSD=	1.1		CSD=	1.2

TABLE 12. INDEPENDENTLY CHOSEN CONTROL POINTS (LATITUDE, LONGITUDE, ROW2, COL2) COMPARED WITH LANDSAT COORDINATES (ROW1, COL1) DETERMINED FROM P-FORMAT REGISTRATION FOR DATA SET 10

	LATITUDE	LONGITUDE	ROW1	ROW2	ROW1-ROW2	COL1	COL2	COL1-COL2
1	34.05809	-82.0828	2638.1	2642.0	-3.9	386.6	384.0	2.6
2	34.05219	-82.2408	2695.7	2699.0	-3.3	137.0	136.0	1.0
3	35.20169	-81.6653	327.0	327.0	-0.0	637.8	636.0	1.8
4	34.98000	-81.8150	795.3	796.0	-0.7	482.3	481.0	1.3
5	34.50609	-81.6597	1715.1	1718.0	-2.9	581.5	579.0	2.5
6	34.16170	-81.9075	2388.1	2392.0	-3.9	628.7	627.0	1.7
7	35.11780	-81.5761	460.9	461.0	-0.1	808.3	807.0	1.3
8	34.37920	-81.6803	1904.4	1907.0	-2.6	911.3	907.0	4.3
9	34.18390	-81.7256	2291.4	2295.0	-3.6	909.9	906.0	3.9
10	34.14059	-81.6306	2345.7	2349.0	-3.3	1076.6	1074.0	2.6
11	35.16609	-81.0383	205.8	210.0	-4.2	1634.7	1632.0	2.7
12	35.26059	-81.1000	44.2	45.0	-0.8	1502.8	1504.0	-1.2
13	35.10059	-81.0400	331.4	335.0	-3.6	1656.5	1655.0	1.5
14	35.01920	-81.0064	476.6	481.0	-4.4	1739.7	1738.0	1.7
15	34.98470	-80.9747	532.7	536.0	-3.3	1802.5	1797.0	5.5
16	34.91109	-80.9683	671.3	674.0	-2.7	1840.1	1836.0	4.1
17	34.18030	-81.1792	2132.4	2136.0	-3.6	1779.1	1776.0	3.1
18	34.14560	-81.2381	2216.8	2220.0	-3.2	1698.4	1693.0	5.4
19	34.02530	-81.2397	2447.1	2454.0	-6.9	1740.4	1736.0	4.4
20	34.04669	-81.1833	2388.9	2394.0	-5.1	1822.1	1817.0	5.1
21	34.02559	-81.1281	2412.2	2418.0	-5.8	1917.7	1914.0	3.7
22	34.69170	-80.7878	1034.2	1038.0	-3.8	2206.9	2204.0	2.9
23	34.43610	-80.7750	1518.2	1521.0	-2.8	2323.8	2320.0	3.8
24	34.14220	-80.7508	2071.7	2077.0	-5.3	2473.4	2469.0	4.4
25	34.05919	-80.8167	2250.9	2257.0	-6.1	2400.1	2396.0	4.1
26	33.91499	-80.7958	2519.7	2525.0	-5.3	2487.8	2482.0	5.8
27	33.76529	-80.8211	2775.3	2780.0	-4.7	2496.5	2492.0	4.5
28	34.46829	-80.1686	1263.8	1269.0	-5.2	3269.8	3266.0	3.8

RBIAS= -3.6 CBIAS= 3.2

RSD= 1.7 CSD= 1.6

TABLE 13. INDEPENDENTLY CHOSEN CONTROL POINTS (LATITUDE, LONGITUDE, ROW2, COL2) COMPARED WITH LANDSAT COORDINATES (ROW1, COL1) DETERMINED FROM P-FORMAT REGISTRATION FOR DATA SET 11

	LATITUDE	LONGITUDE	ROW1	ROW2	ROW1-ROW2	COL1	COL2	COL1-COL2
1	41.03639	-94.2000	92.4	90.0	2.4	466.8	469.0	-2.2
2	40.99809	-94.2236	363.4	361.0	2.4	486.2	490.0	-3.8
3	40.79639	-94.3381	591.2	589.0	2.2	359.4	363.0	-3.6
4	40.21169	-94.3836	1721.2	1719.0	2.2	517.8	521.0	-3.2
5	39.98109	-94.5292	2204.5	2202.0	2.5	392.4	393.0	-0.6
6	39.62360	-94.5564	2904.2	2904.0	0.2	444.1	442.0	2.1
7	40.90059	-94.0711	313.6	310.0	3.6	706.2	709.0	-2.8
8	40.57439	-93.9742	907.2	905.0	2.2	974.6	976.0	-1.4
9	40.24750	-94.0600	1556.7	1554.0	2.7	977.5	979.0	-1.5
10	40.72629	-93.7050	532.5	529.0	3.5	1304.8	1305.0	-0.2
11	40.69579	-93.5653	551.9	550.0	1.9	1520.5	1522.0	-1.5
12	39.90919	-93.6361	2134.3	2131.0	3.3	1438.8	1437.0	1.8
13	39.63920	-93.7014	2798.4	2797.0	1.4	1784.1	1781.0	3.1
14	40.65939	-93.0783	89.5	85.0	4.5	2159.3	2159.0	0.3
15	40.66279	-93.2119	124.7	121.0	3.7	1964.8	1966.0	-1.2
16	40.78690	-93.1397	246.7	243.0	3.7	2100.3	2100.0	0.3
17	39.65869	-93.4789	2501.2	2498.0	3.2	2064.2	2062.0	2.2
18	39.42029	-93.4753	2954.7	2952.0	2.7	2165.8	2162.0	3.8
19	40.58669	-92.9847	579.2	577.0	2.2	2407.6	2409.0	-1.[illegible]
20	40.23940	-92.3503	1229.3	1229.0	0.3	2601.6	2603.0	-1.[illegible]
21	39.84419	-93.2033	2633.0	2631.0	2.0	2517.0	2513.0	4.0
22	39.43109	-93.0775	2808.3	2805.0	3.3	2749.0	2746.0	3.0
23	40.30060	-92.5703	990.9	992.0	-1.1	3129.8	3130.0	-0.2
24	40.16779	-92.5433	1234.6	1235.0	-0.4	3225.4	3226.0	-0.6
25	40.22609	-92.7336	1185.3	1186.0	-0.7	2923.2	2924.0	-0.8
26	39.94780	-92.6597	1690.7	1692.0	-1.3	3148.1	3147.0	1.1
27	39.75999	-92.6917	2058.2	2056.0	2.2	3180.2	3178.0	2.2
28	39.41640	-92.3950	2777.6	2774.0	3.6	3024.5	3019.0	5.5
29	39.42389	-92.8086	2735.4	2733.0	2.4	3148.9	3145.0	3.9
				RBIAS=	2.1		CBIAS=	0.2
				RSD=	1.5		CSD=	2.5

TABLE 14. INDEPENDENTLY CHOSEN CONTROL POINTS (LATITUDE, LONGITUDE, ROW2, COL2) COMPARED WITH LANDSAT COORDINATES (ROW1, COL1) DETERMINED FROM P-FORMAT REGISTRATION FOR DATA SET 12

	LATITUDE	LONGITUDE	ROW1	ROW2	ROW1-ROW2	COL1	COL2	COL1-COL2
1	38.21719	-98.0869	48.6	38.0	10.6	354.3	347.0	7.3
2	38.10609	-98.0836	260.0	250.0	10.0	400.7	393.0	7.7
3	38.03920	-98.0869	388.9	378.0	10.9	420.6	412.0	8.6
4	38.12999	-97.8608	148.5	142.0	6.5	728.1	719.0	9.1
5	37.92220	-97.9156	561.8	552.0	9.8	723.5	715.0	8.5
6	37.89749	-97.9586	621.8	610.0	11.8	667.7	659.0	8.7
7	37.67580	-97.9356	1038.5	1028.0	10.5	785.7	777.0	8.7
8	37.38440	-98.0731	1636.3	1624.0	12.3	685.5	675.0	10.5
9	37.16640	-98.0572	2048.2	2034.0	14.2	791.0	782.0	9.0
10	37.03580	-98.2028	2341.1	2328.0	13.1	616.7	606.0	10.7
11	38.10559	-97.7456	160.7	151.0	9.7	911.3	903.0	8.3
12	38.04529	-97.6833	257.2	249.0	8.2	1028.2	1018.0	10.2
13	37.79219	-97.7906	772.8	763.0	9.8	961.9	953.0	8.9
14	37.57579	-97.7892	1185.7	1175.0	10.7	1045.9	1037.0	8.9
15	37.54689	-97.8439	1257.4	1246.0	11.4	973.6	965.0	8.6
16	37.13809	-97.9658	2074.9	2063.0	11.9	941.4	932.0	9.4
17	37.43719	-97.8142	1458.0	1447.0	11.0	1060.2	1050.0	10.2
18	38.06389	-97.2781	98.5	91.0	7.5	1632.8	1625.0	7.8
19	38.01140	-97.2797	199.1	192.0	7.1	1650.8	1642.0	8.8
20	37.75639	-97.3467	706.3	698.0	8.3	1648.4	1640.0	8.4
21	37.22939	-97.4619	1747.4	1735.0	12.4	1676.6	1667.0	9.6
22	37.04079	-97.4730	2110.8	2098.0	12.8	1732.2	1722.0	10.2
23	36.64110	-97.5881	2909.2	2893.0	16.2	1708.8	1696.0	12.8
24	37.16939	-97.0428	1731.4	1721.0	10.4	2339.5	2329.0	10.5
25	36.68059	-97.0636	2670.0	2657.0	13.0	2499.6	2490.0	9.6
26	36.57889	-97.0775	2868.3	2857.0	11.3	2518.1	2510.0	8.1
27	37.67920	-96.8436	696.7	689.0	7.7	2441.0	2434.0	7.0
28	37.43279	-96.9730	1207.3	1197.0	10.3	2342.1	2333.0	9.1
29	37.81720	-96.2342	238.4	232.0	6.4	3307.3	3301.0	6.3
				RBIAS=	10.5		CBIAS=	9.0
				RSD=	2.3		CSD=	1.3

TABLE 15. SUMMARY OF TABLES 3-14

DATA SET	LANDSAT MISSION NO.	ASSESSMENT NUMBER	DATE GEN BY MDP	RBIAS	RSD	CBIAS	CSD
1	2	5	7/23/79	0.5	1.1	-0.3	1.3
2	2	4	7/29/79	0.9	2.4	0.1	1.1
3	2	1	8/30/79	0.2	1.3	-0.2	1.0
4	3	2	4/23/80	15.8	3.9	0.6	1.7
5	2	1	5/18/80	-414.8	5.3	9.2	0.9
6	2	0	5/18/80	-407.4	4.2	9.5	1.0
7	2	3	5/12/79	0.7	1.1	1.4	1.0
8	3	2	6/4/79	1.3	1.1	-0.8	1.2
9	3	2	9/15/80	0.3	1.1	-0.8	1.[illegible]
10	3	3	2/15/80	-3.6	1.7	3.2	1.6
11	2	2	8/5/79	2.1	1.5	0.2	2.5
12	2	4	5/28/80	10.5	2.3	9.0	1.3

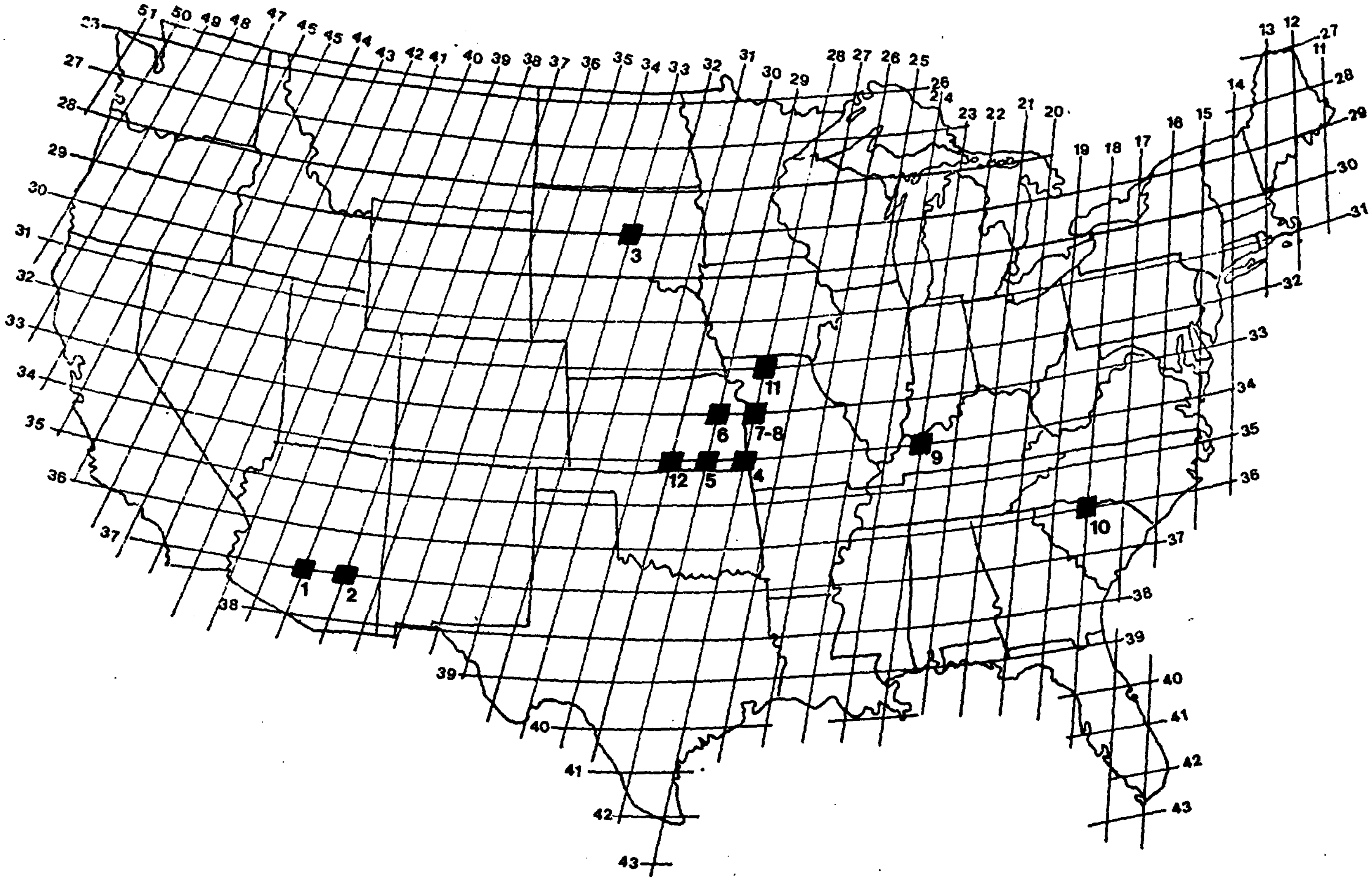

Figure 1. Distribution of 12 Landsat scenes according to path and row numbers

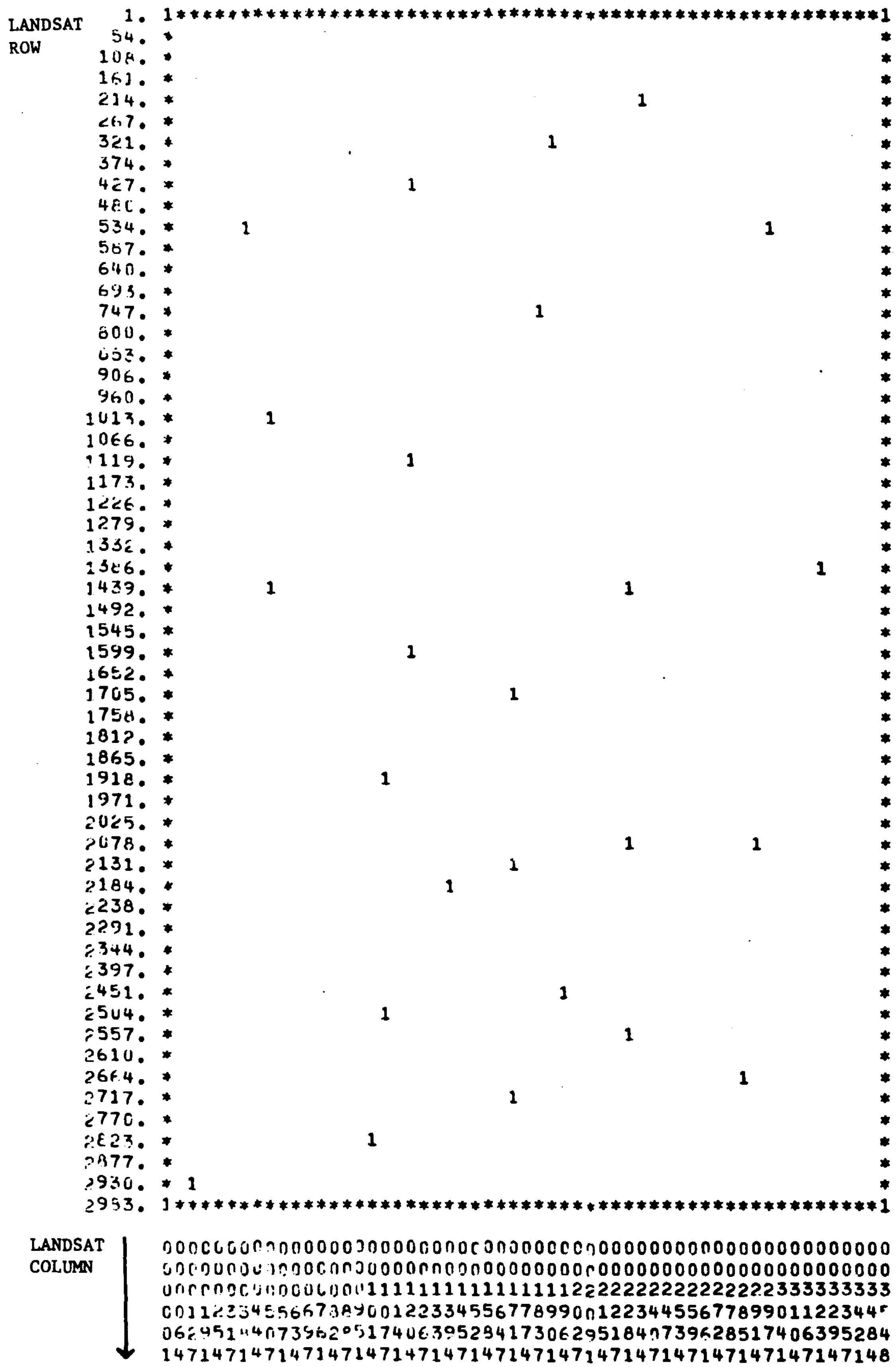

Figure 2. Relative distribution of independently chosen control points for data set 1

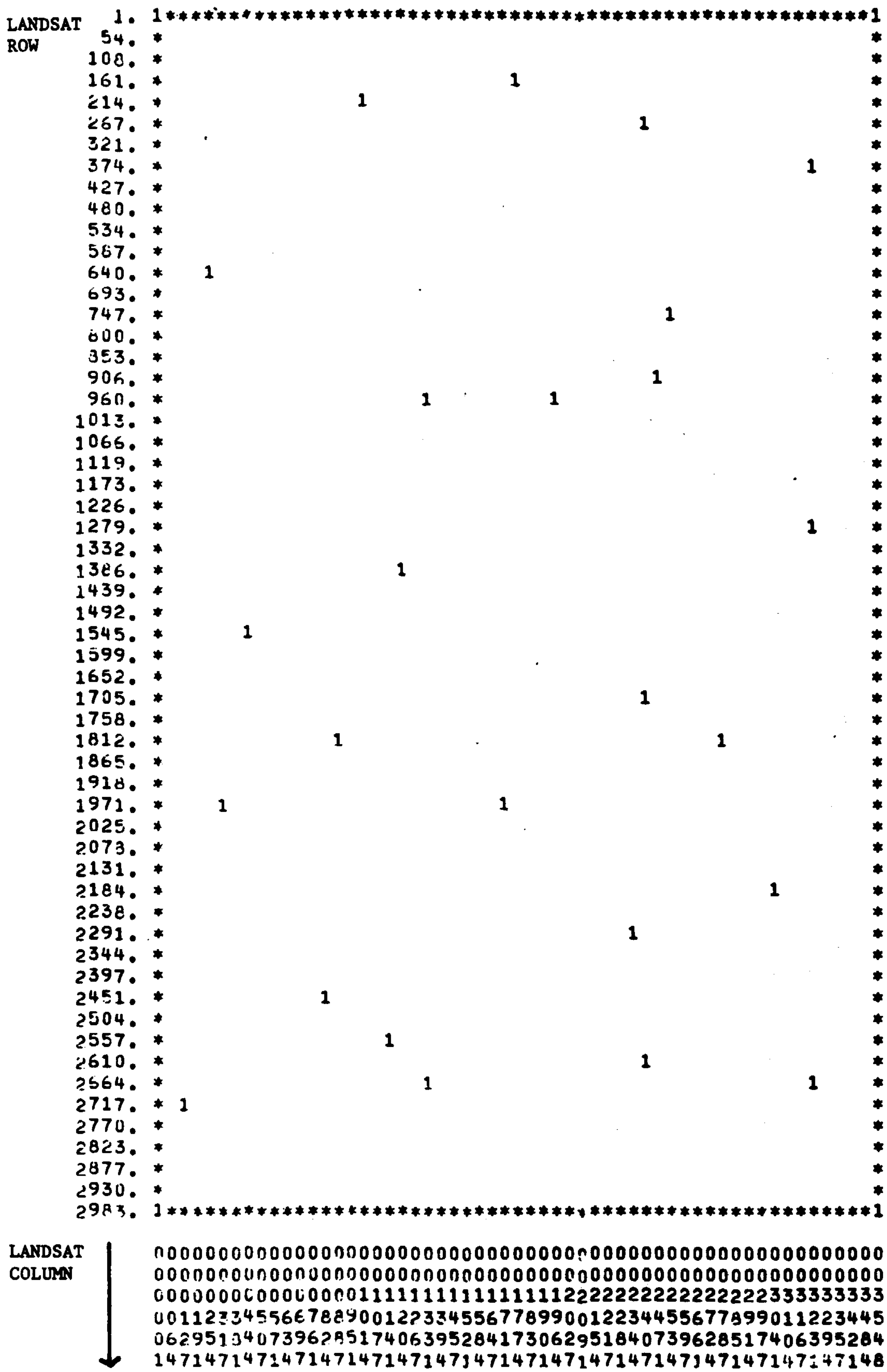

Figure 3. Relative distribution of independently chosen control points for data set 2

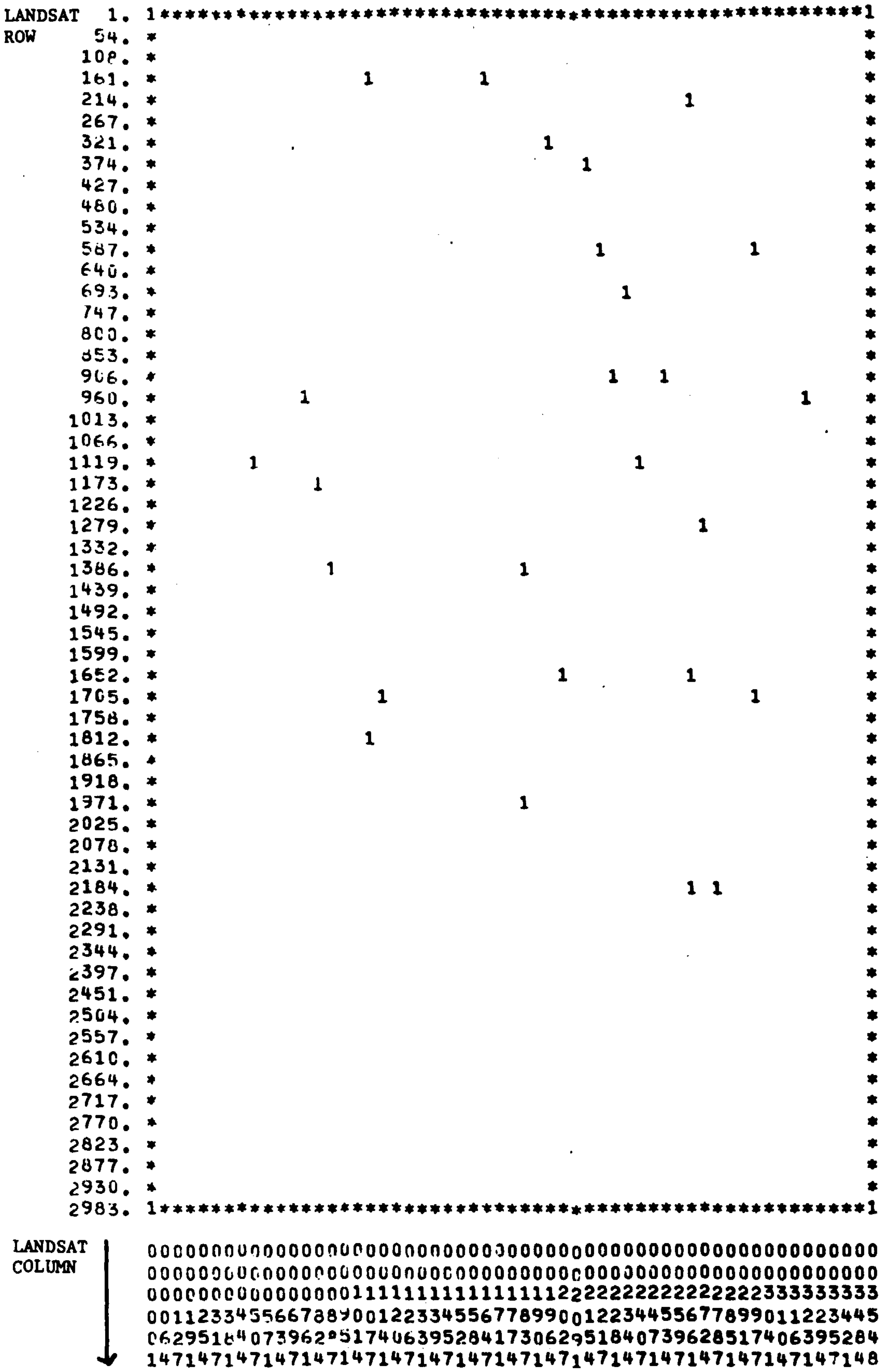

Figure 4. Relative distribution of independently chosen control points for data set 3

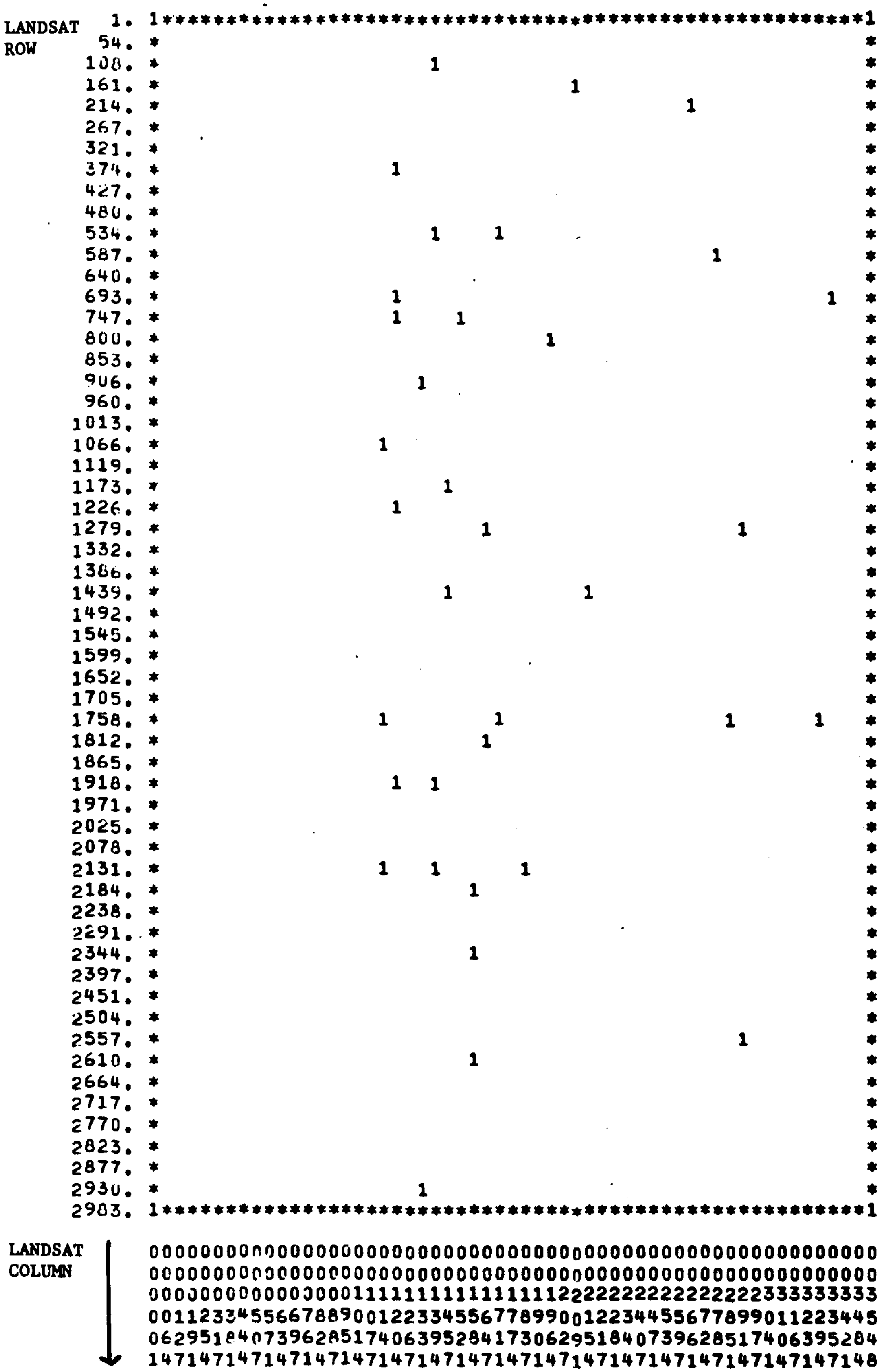

Figure 5. Relative distribution of independently chosen control points for data set 4

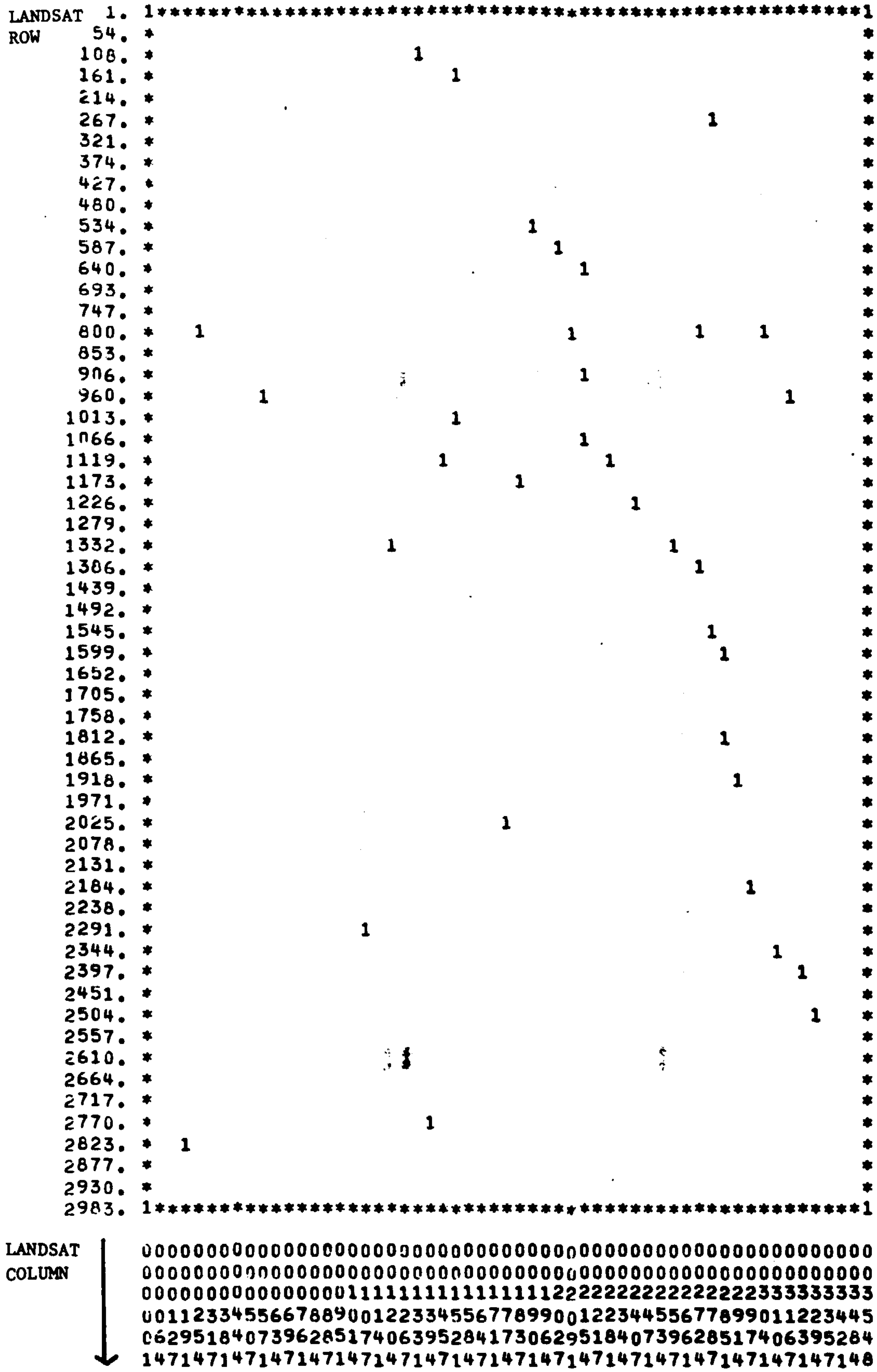

Figure 6. Relative distribution of independently chosen control points for data set 5

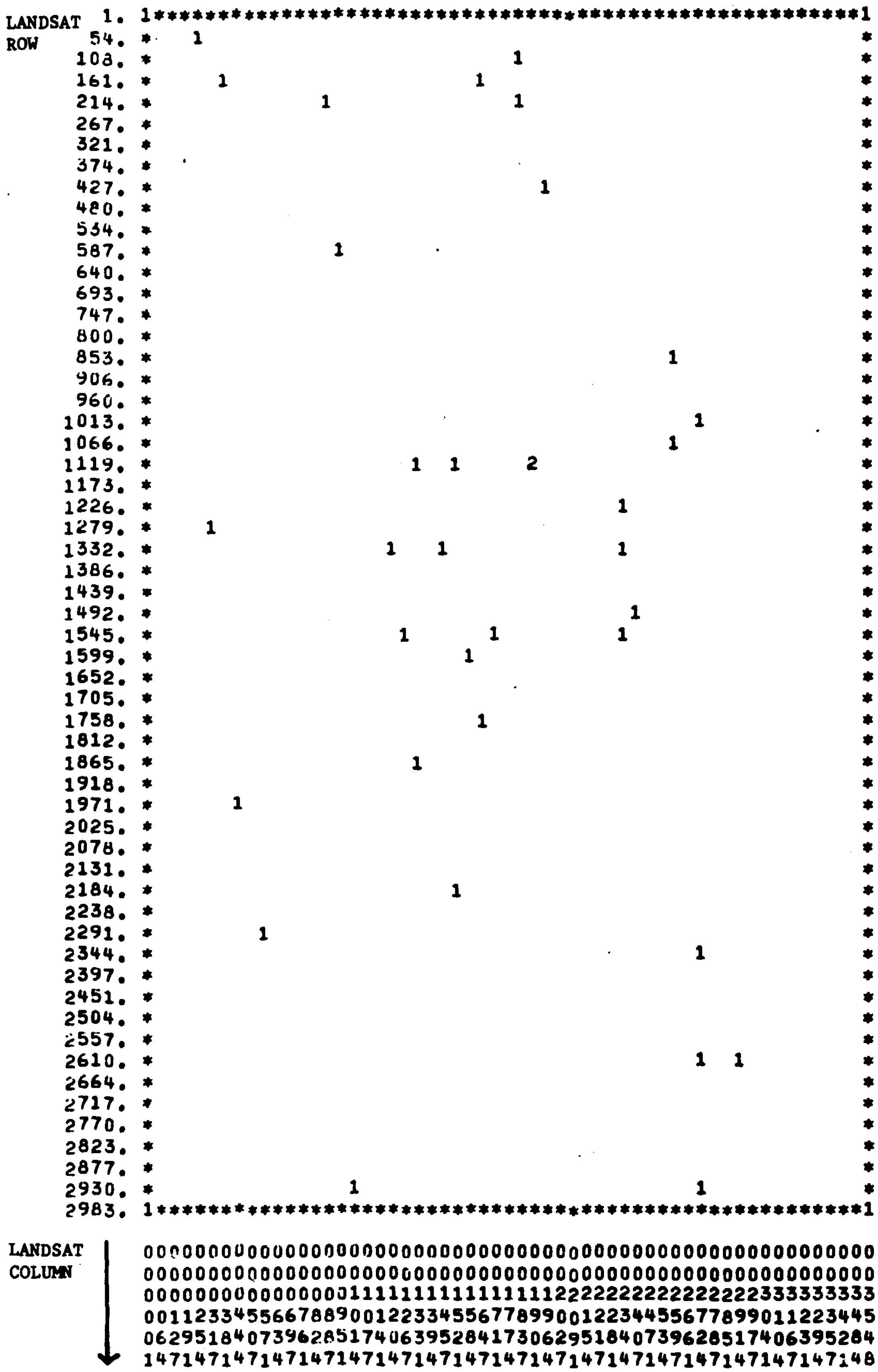

Figure 7. Relative distribution of independently chosen control points for data set 6

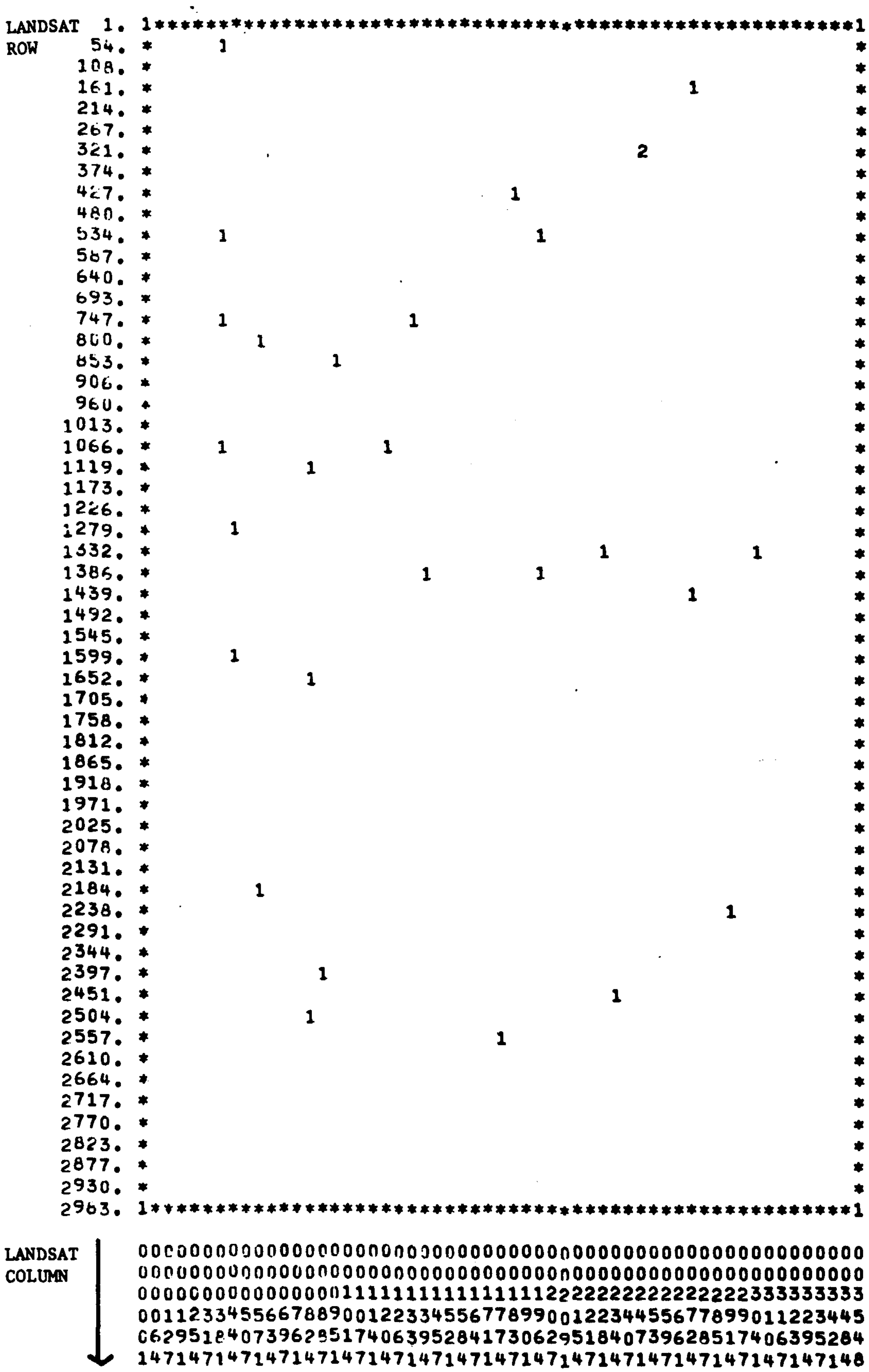

Figure 8. Relative distribution of independently chosen control points for data set 7

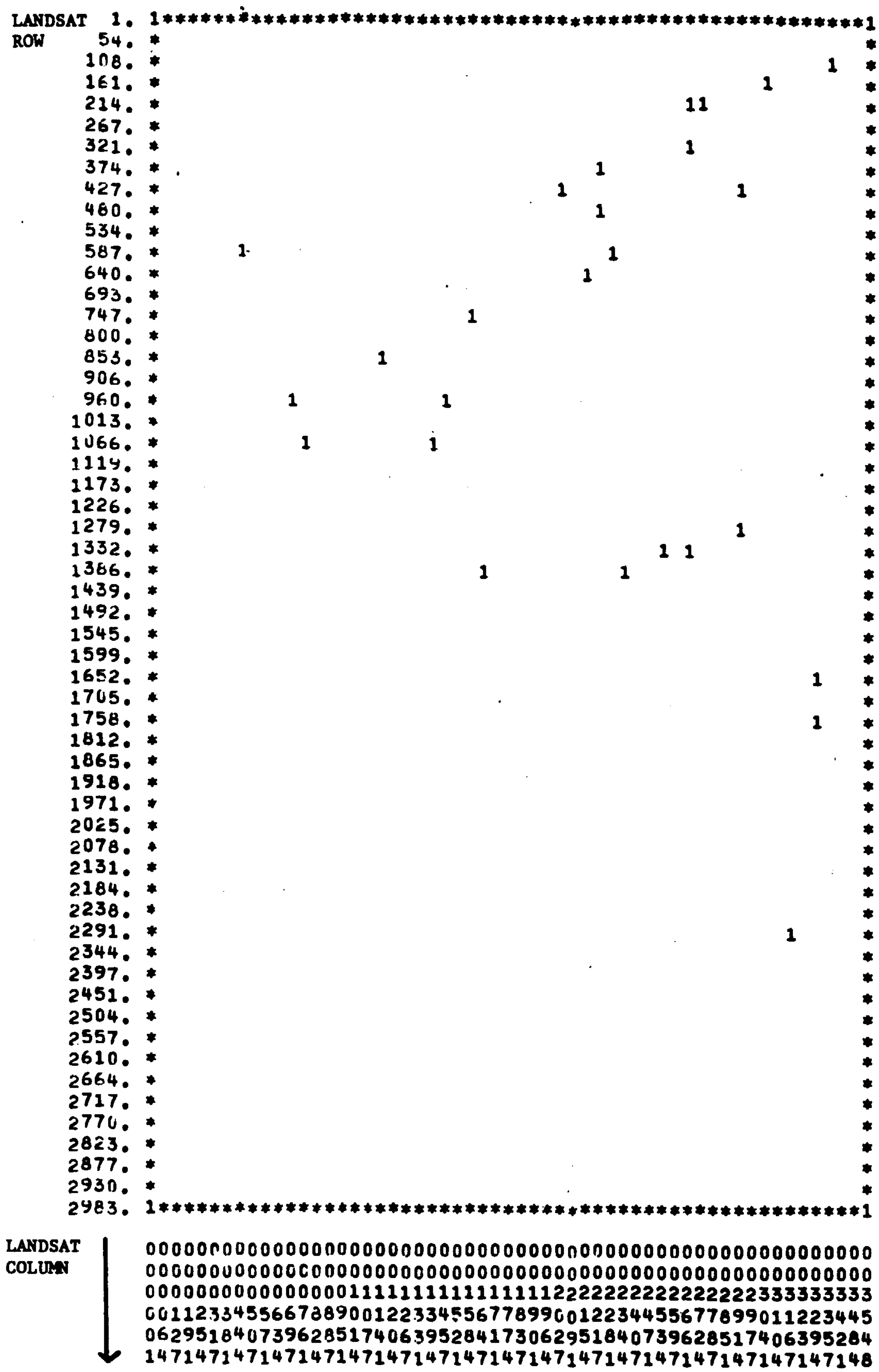

Figure 9. Relative distribution of independently chosen control points for data set 8

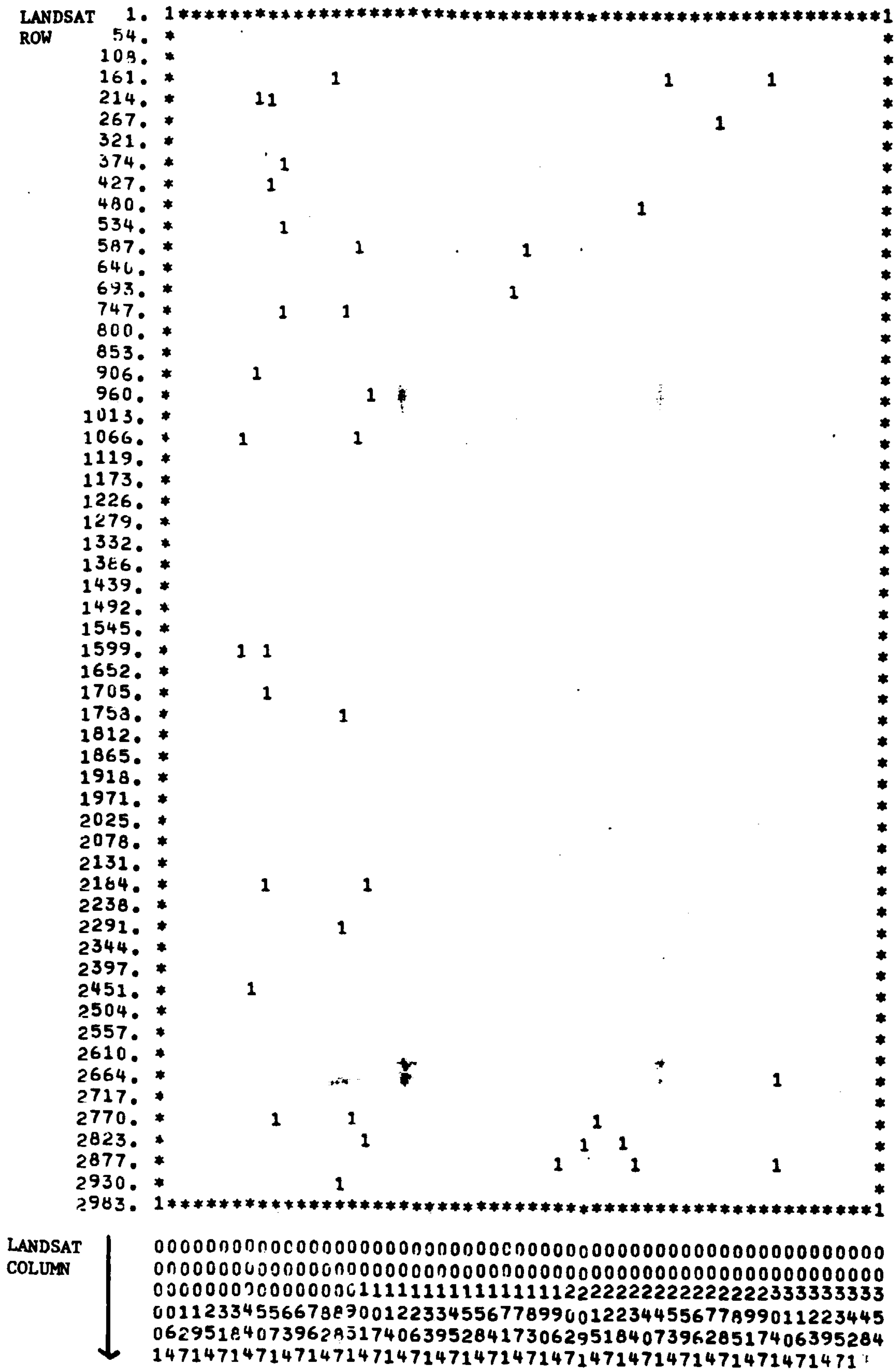

Figure 10. Relative distribution of independently chosen control points for data set 9

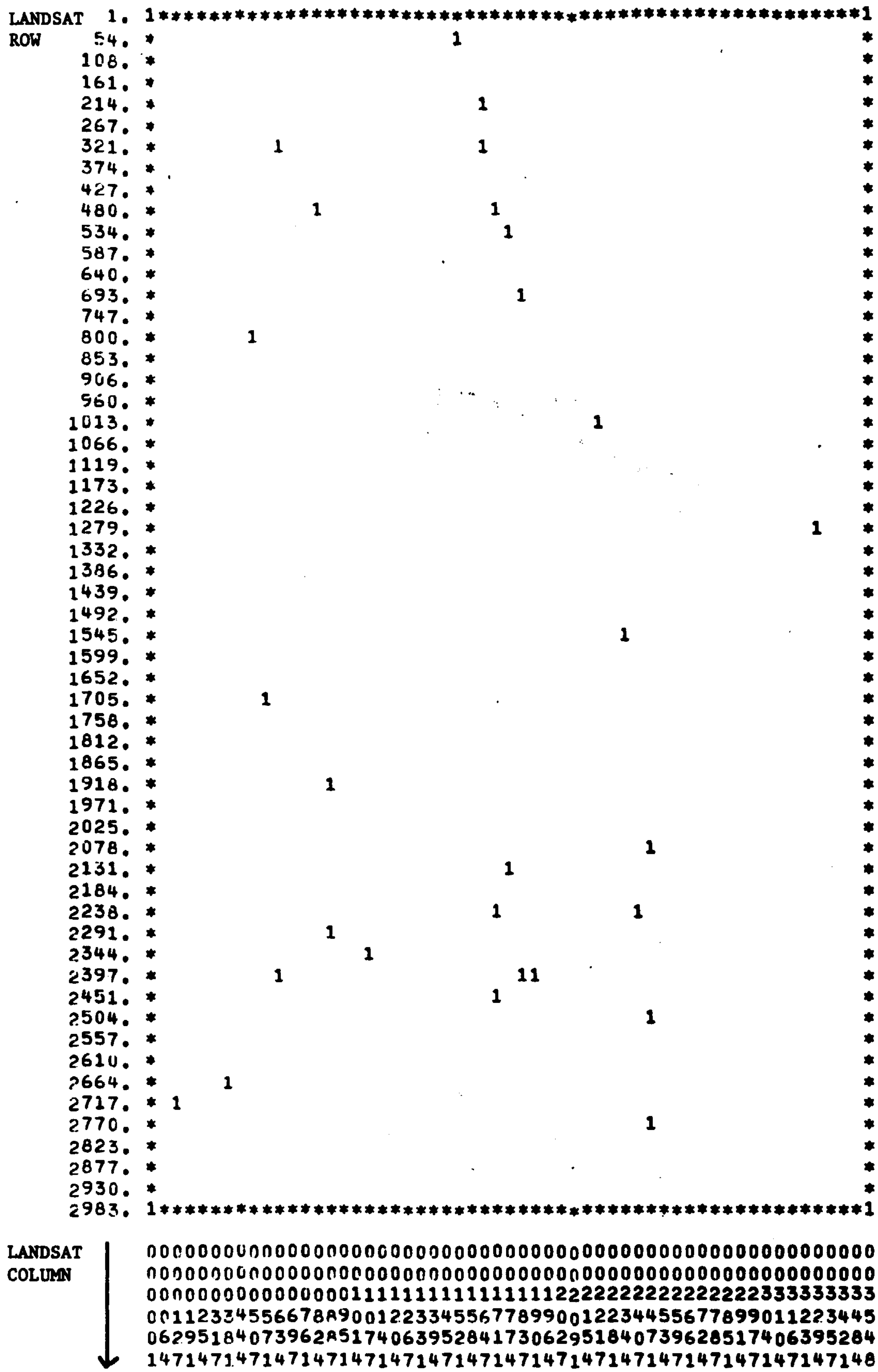

Figure 11. Relative distribution of independently chosen control points for data set 10

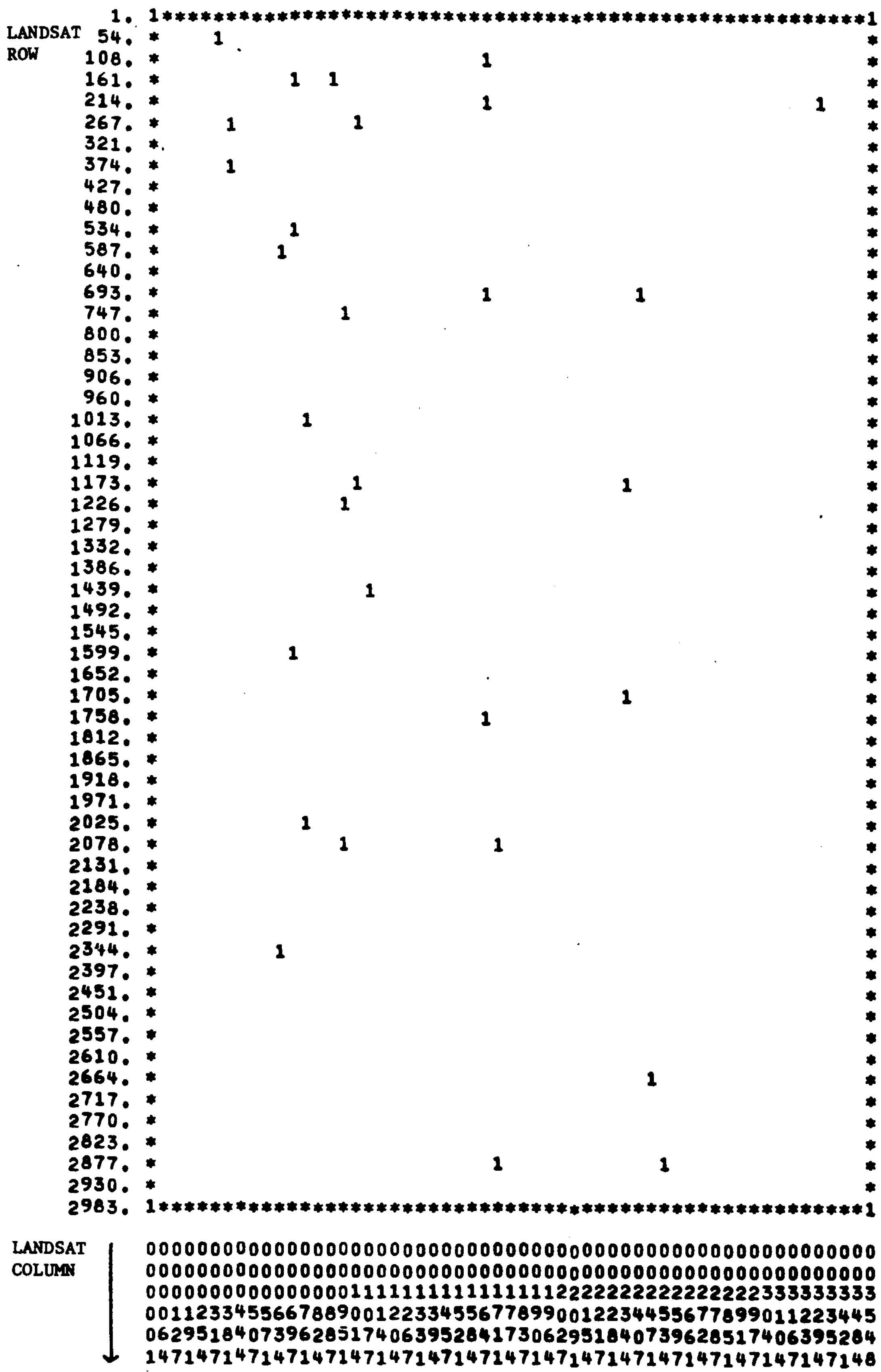

Figure 13. Relative distribution of independently chosen control points for data set 12

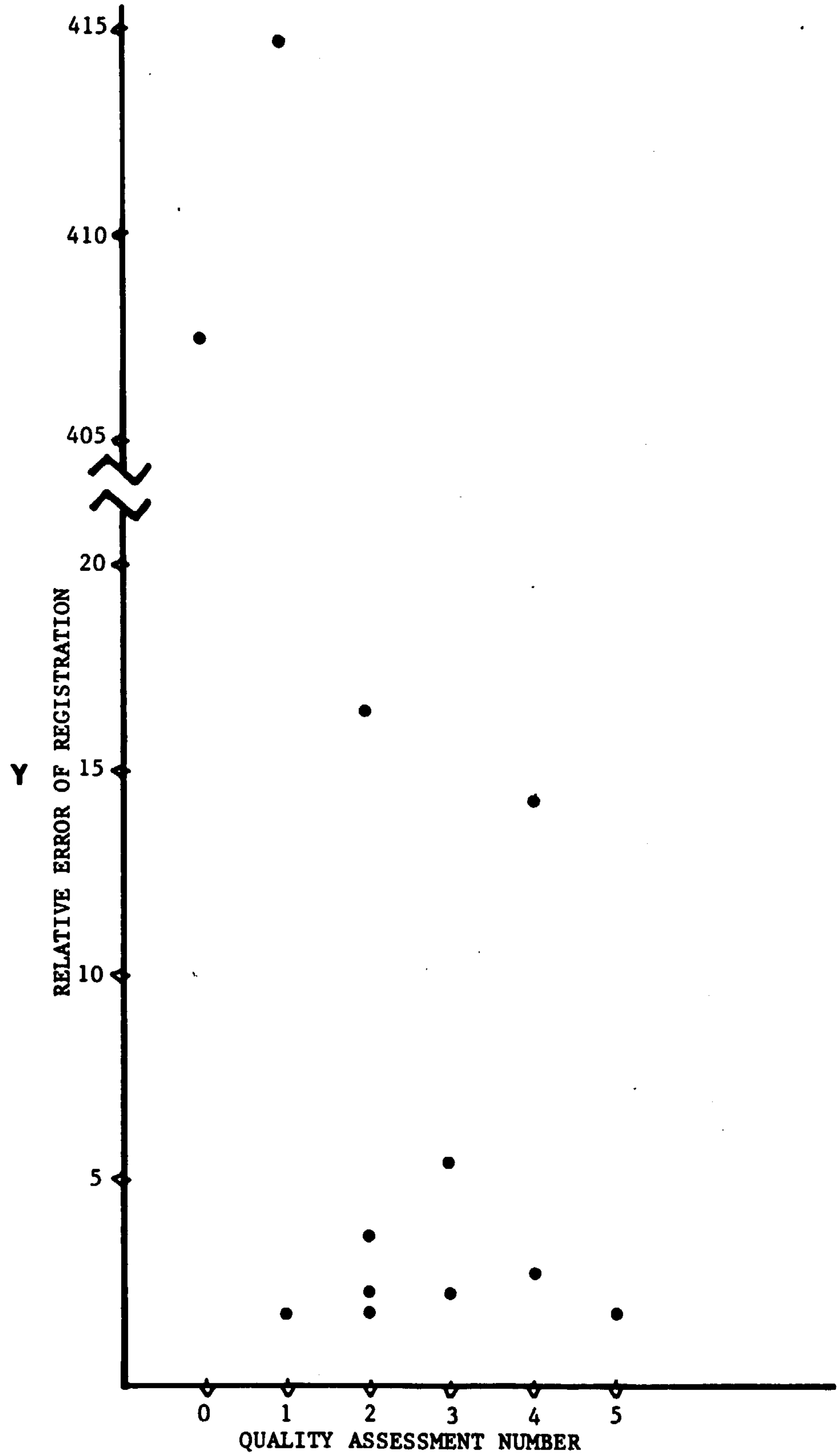

Figure 14. Quality assessment number versus relative error of registration value Y $(Y = \sqrt{(RBIAS)^2+(RSD)^2+(CBIAS)^2+(CSD)^2}$, where RBIAS, RSD, CBIAS, and CSD are values from table 15)

APPENDIX

ICS 1-19

January 16, 1980

TO: 415/OPS/A Project Manager

FROM: 563/Head, Image Processing Branch

SUBJECT: Geometric Correction Errors Noted by the EROS Data Center (EDC)

As noted by the EDC there is a discrepancy between the number of Ground Control Points (GCPs) indicated to be involved in the geometric correction algorithms and the actual count.

During the period from June 14, 1979, to August 1, 1979, a patch was used on the Master Data Processor (MDP) to resolve an infrequent timing problem. When this patch is used, all GCPs are bypassed, however, this is not properly indicated in the header or annotation records.

It should be assumed that all data processed with this patch has been processed using systematic corrections (accurate to 2.7 km) not with GCPs; this will eliminate the possibility of error.

A listing of all P-tapes produced using the special GCP patch is attached. All other P-tapes are properly annotated.

Marc Jay Selig

Marc Jay Selig

Attachment

cc: Dr. Freden/902
Mr. Holmes/563
Mr. Tinsley/563
Mr. Thomson/EDC

CSTA COMPUTER SCIENCES — TECHNICOLOR ASSOCIATES

INTEROFFICE CORRESPONDENCE

to M. Selig from N. Vredenburg/B. Horn date January 15, 1980

N. B.H.

subject Landsat P-Tapes with GCP Errors in Header Records

A patch used to correct an "error return from RSS" on the MDP which caused GCP error count in the HDT-PM header records was used in production from June 14, 1979 to August 1, 1979.

The following HDT-PM tapes were made with the patch:

L3MHP79166-09
L3MHP79168-02
L2MHP79168-03
L3MHP79168-04
L2MHP79169-03
L2MHP79171-07
L2MHP79171-08
L2MHP79171-09
L3MHP79171-10
L3MHP79173-04
L3MHP79173-06
L3MHP79173-07
L3MHP79173-08
L2MHP79173-09
L3MHP79180-57
L2MHP79182-55
L2MHP79177-51
L2MHP79177-52
L3MHP79207-01
L2MHP79207-04
L2MHP79207-06
L3MHP79208-04
L2MHP79208-07
L2MHP79208-08
L2MHP79210-08
L2MHP79211-05
L2MHP79211-01
L3MHP79213-07
L2MHP79213-01

Total = 29 tapes

NV/BH:ncn

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2. "Landsat 3 Light-Source Problem," Landsat Data Users Notes, Issue No. 14, U.S. Department of the Interior, U.S. Geological Survey, EROS Data Center, Sioux Falls, SD, September 1980, p. 7.

3. Landsat Data Users Handbook, Revised Edition, U.S. Department of the Interior, U.S. Geological Survey, Arlington, VA, 1979, pp. 7-19.

4. "EDIPS Image Accuracy Tests," Landsat Data Users Notes, Issue No. 9, U.S. Department of the Interior, U.S. Geological Survey, EROS Data Center, Sioux Falls, SD, November 1979, p. 4.

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6. "The Hotine Oblique Mercator Projection," Landsat Data Users Notes, Issue No. 11, U.S. Department of the Interior, U.S. Geological Survey, EROS Data Center, Sioux Falls, SD, March 1980, pp. 4-5.