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The Use of Landsat-4 MSS Digital Data in Temporal Data Sets and the Evaluation of Scene-to-Scene Registration Accuracy

By utilizing electrostatic grey-tone plots and an X-Y digitizer, an independent estimate of Landsat MSS scene-to-scene registration accuracy can be obtained.

Abstract: *The* MSS *sensor on Landsat-4 is, in certain performance aspects, different from those on Landsats 1 through 3. These differences have created some concern in the* NASA *research community as to whether individual data sets can be registered accurately enough to produce acceptable data for multitemporal data analysis. This study examines the use of Landsat-4* MSS *digital data in temporal data sets, and presents a method for estimating temporal registration accuracy based on the use of an* X-Y *digitizer and grey tone electrostatic plots. Results obtained from temporal data sets generated using* NASA/*National Space Technology Laboratories Earth Resources Laboratory software indicate that the* RMS *temporal registration errors were not significantly different between the temporal data sets generated using Landsat-4 and Landsat-2 data (33.35 metres) and the temporal data set constructed from two Landsat-2 data sets (33.61 metres). A derivation of the model used to evaluate the temporal registration is included.*

Introduction

The purpose of multitemporal registration, using data from a sensor such as the Landsat Multispectral Scanner (MSS), is to produce a single multichannel data set from two or more individual multichannel data sets separated in time. The data from one date are used as a base and all other data are fitted or mapped onto them. It is generally accepted that, by producing such a temporal data set, researchers can capitalize on changes which occur (or do not occur) over the time frame encompassed, thus gaining an added dimension that will lead to improvements in the utility of the data being examined. For example, studies by Badhwar *et al.* (1982) and Hay *et al.* (1982) describe the use of temporal agronomic crop signatures which characterize Landsat MSS data values as functions of crop phenology or growth state. Such temporal analyses have produced results which are significantly better than those obtained with single-date data sets. Mergerson (1981) points out that, as a result of better discrimination, multidate data sets produce improved crop area estimates. Representative research in the application of multitemporal data for investigations in Forestry (Lee, 1980), Hydrology (Saito *et al.*, 1982), Ice and Snow Field studies (Dey, 1980), Wetlands and Coastal Processes (Lim *et al.*, 1980), Land Cover Dynamics (Byrne *et al.*, 1980), and Land-Use Mapping/Natural Resources Inventories (Lichtenegger and Seidel, 1981) have demonstrated the widespread interdisciplinary utility of temporal data.

Results obtained from the use of temporal data

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are related to the degree to which two or more data sets can be registered one to another; the better the registration, the better the expected results. Registration errors can arise from numerous sources. Of particular interest to this study are registration errors which might be caused by differences in the sensor being used.

By design, sensor or platform differences between the first three Landsat satellites were insignificant and, thus, MSS data registration errors induced by satellite system differences were minimal. However, the Landsat-4 MSS is in at least two respects different from its predecessors. First, the scan angle is wider (14.9 degrees versus 11.6 degrees), and second, the instantaneous field of view (ground resolvable area) is slightly different (82.7 by 57 metres versus 79 by 56 metres). Software at the ground processing facility of the NASA Goddard Space Flight Center (GSFC) has been designed to produce "standardized" P-format digital data from the raw Landsat-4 MSS data. However, there has been some concern expressed about whether the registration of temporal data sets, which include Landsat-4 MSS data, has been adversely affected (NASA, 1981). GSFC therefore encouraged research in constructing temporal data from Landsat-4 MSS and Landsat 1 through 3 MSS data, through the NASA-sponsored Landsat-D Image Data Quality Analysis (LIDQUA) Program, to verify continuity of this feature. As its commitment to the LIDQUA Program, NASA's Earth Resources Laboratory, located at the National Space Technology Laboratories (NASA/NSTL/ERL), has conducted temporal registration assessment research using Landsat-4 MSS data.

TECHNICAL APPROACH

GENERATION OF TEMPORAL DATA SETS

The procedures for generating temporal data sets are well documented in the literature (see especially Bryant (1982) for a summary). However, a brief discussion of the specific technique as implemented at NASA/NSTL/ERL is warranted.

The first step in producing a temporal data set is to choose a "base" and a "map" data set. In the context of this paper, base data is used "as is;" i.e., it furnishes the scan line and pixel coordinate system onto which the map data will be fitted. The map data set(s) is therefore the set which is contorted (stretched/shrunk) to overlay the base data set. After designating the base and map data sets, six to ten uniformly distributed points which represent unambiguous scene locations are located in both data sets. The scan line/pixel coordinates of the points (for both data sets) are used to compute an initial set of least-squares mapping equations. Such equations define the fundamental relationship between points located in the map data set and identical locations in the base data set.

Based on the initial mapping equations, correlation software is used to locate 100 to 200 additional points which represent common geographic locations in both data sets. Initially, points are located in the base data set, and a window of data centered on each base point is extracted. For each such point in the base data set, the initial mapping equations are used to calculate an expected location in the map data set. A sliding window the same size as used in the base data is then moved around the expected location in the map data set, moving one pixel or scan line at a time. Each movement results in the extraction of a slightly different digital count data sample, and the simple correlation of each map data sample (grey levels) with the base data sample is computed. It is assumed that differences in dates will be minimized by the use of grey-level correlation. The coordinates (to the nearest scan line and element) of the pixel located at the center of the window in the map data with the highest correlation coefficient to the corresponding window of base data is retained as the most probable location for a matching point. If the distance between pixels in the base and map data sets is greater than a user defined value, the point is automatically discarded. This procedure continues until all points located in the base data set have been processed.

Points located by the correlation software are manually edited, because some points may not adequately depict the relationship between the base and map data sets. Those which are found to be questionable are deleted and a final set of least-squares mapping equations is generated along with a root-mean-square (RMS) registration error that is computed using the retained control points. Temporal registration is then accomplished using a piecewise fit with bilinear resampling. The piecewise fit subdivides the image into sixteen zones, and a least-squares fit is performed using a constant to weight the control points within a zone, and a weight of $1/(\text{distance})^2$ for points outside the zone. It has been demonstrated that this technique produces results which in five out of eight test cases were significantly better than cubic polynomial fits (Seyfarth and Cook, 1981). Bilinear resampling was chosen due to economic reasons, although a cubic convolution approach would generate a sharper resampled data set.

REGISTRATION EVALUATION METHODOLOGY

In order to evaluate the level of temporal registration success, a technique has been developed at NASA/NSTL/ERL which relies on the use of an *X-Y* digitizer and electrostatic grey-level plots. Numerous randomly located subscene areas (approximately 512 scan lines by 512 pixels in size) are located in the newly constructed temporal data set. Three digital count-to-grey-level plots are generated for each subscene area chosen, one plot for each of two channels of the original base data, and one plot for a single channel of the mapped data set after the map data set has been resampled. The channels selected are typically MSS channel 5 (0.7 to 0.8 micrometre wavelength region) or MSS channel 7 (0.8 to 1.1 micrometre wavelength region) for the base data, and the corresponding channel for the mapped data. Because the plots are generated from the temporal data set, scan line/pixel coordinates are identical for all plots of a specific subscene area; i.e., the scan lines/pixels of the mapped data are now in terms of base data coordinates, because the remapping has already taken place.

For each subscene area used, the corresponding plots are simultaneously mounted on the table of an X-Y digitizer. After initializing the digitizer to the plots, overlay assessment (OA) points, which are unambiguously identifiable on all three plots, are located and their scan line/pixel coordinates are recorded using the digitizer. For each OA point located, three sets of scan line/pixel coordinates are generated, because three plots are used (the base channel is repeated in order to estimate the human factor described later). All coordinates are stored by sample number for subsequent use.

The digitized coordinates are then processed by statistical analysis software, which computes the statistics defining the RMS error associated with the temporal data set examined. The software is unique in that it computes total error, errors associated with human location of OA points, and an estimate of actual temporal registration error (which can be thought of as total error minus the human error). The following discussion is an amplification of the analysis model originally designed by Seyfarth and Cook (1981).

The model employed assumes that, for each point sampled,

$$X_{b1i} = X_i + E_{b1i}$$

where X_{b1i} is the pixel coordinate for the i^{th} OA test point in the first channel of the base data set used, X_i is the theoretically true location of the i^{th} test point, and E_{b1i} is the human error associated with selecting that test point. This assumption applies to the second base channel used as well as to the mapped channel and yields

$$X_{b2i} = X_i + E_{b2i}, \text{ and}$$
$$X_{mi} = X_i + E_{mi} + \alpha_i$$

where X_{b2i} and X_{mi} are the X coordinates for the i^{th} point from the second base channel used and the mapped data channel, respectively; E_{b2i} and E_{mi} represent the human error contribution for the i^{th} point selected from the second base channel used and the mapped data channel, respectively; and α_i is the actual misregistration at the i^{th} point. It is also assumed that E_{b1}, E_{b2}, E_m, and α are all independent random variables, normally distributed with means of zero and variances σ^2_{xb1}, σ^2_{xb2}, σ^2_{xm}, and $\sigma^2_{x\alpha}$, and that σ^2_{xb1}, σ^2_{xb2}, and σ^2_{xm} are all equal to σ^2_{xh}, which is associated with the human error component. (All through this discussion similar formulae could be derived for the scan line (Y) component, but for the sake of brevity such derivations will not be explicitly made.)

Because X_{b1i} and X_{b2i} represent coordinates of the same point chosen from two channels of the base data set, consider

$$\sum_{i=1}^{n} \frac{(X_{b1i} - X_{b2i})^2}{n}$$

which can be expanded to yield

$$\sum_{i=1}^{n} \frac{(X_i + E_{b1i} - X_i - E_{b2i})^2}{n} .$$

The assumption of independence leads to

$$\sum_{i=1}^{n} \frac{{E_{b1i}}^2}{n} + \sum_{i=1}^{n} \frac{{E_{b2i}}^2}{n}$$
$$= \sigma^2_{xb1} + \sigma^2_{xb2}$$
$$= 2\sigma^2_{xh}$$

So an estimate for the human error component is

$$\sigma^2_{xh} = \frac{1}{2} \sum_{i=1}^{n} \frac{(X_{b1i} - X_{b2i})^2}{n} .$$

The coordinate derived from the map channel (X_{mi}) is used as follows. Consider the difference between the X_{mi} and the average of X_{b1i} and X_{b2i}:

$$\sum_{i=1}^{n} \left[\frac{X_{mi} - \dfrac{(X_{b1i} + X_{b2i})}{2}}{n} \right]^2$$

$$= \frac{1}{n} \sum_{i=1}^{n} \left[X_i + E_{mi} + \alpha_i - \frac{(X_i + E_{b1i} + X_i + E_{b2i})}{2} \right]^2$$

$$= \frac{1}{n} \sum_{i=1}^{n} \left[E_{mi} + \alpha_i - \left(\frac{E_{b1i}}{2} - \frac{E_{b2i}}{2} \right) \right]^2$$

The assumption of independence yields

$$\sum_{i=1}^{n} \frac{{E_{mi}}^2}{n} + \sum_{i=1}^{n} \frac{\alpha_i^2}{n} + \frac{1}{4} \sum_{i=1}^{n} \frac{{E_{b1i}}^2}{n} + \frac{1}{4} \sum_{i=1}^{n} \frac{{E_{b2i}}^2}{n}$$

TABLE 1. DATA SOURCES FOR THE TEMPORAL REGISTRATION INVESTIGATION

Landsat MSS	Date	Scene ID	Comments
2	Sept 1980	22063-15500	Served as the base data set for the study
2	Feb 1981	22225-15485	
4	Sept 1982	40062-15591	Scene produced using pre-launch software parameters at NASA/Goddard Space Flight Center
4	Mar 1983	40238-16010	Modified software parameters used

which is identical to

$$\sigma_{xh}^2 + \sigma_\alpha^2 + \frac{1}{2}\sigma_{xh}^2.$$

After replacing σ_{xh}^2 with its earlier derived equivalent and rearranging terms, we get

$$\sigma_\alpha^2 = \sum_{i=1}^{n} \frac{X_{mi} - \dfrac{(X_{b1i} - X_{b2i})^2}{2}}{n} - \frac{3}{4}\sum_{i=1}^{n} \frac{(X_{b1i} - X_{b2i})}{n}.$$

In order to obtain the error in terms of metres (because σ_{xh} and σ_α are in terms of pixels)

$$\sigma_{x(\text{metres})} = 57\sigma_\alpha \quad \text{for P-format Landsat MSS data.}$$

As previously mentioned, a similar formula could be derived for $\sigma_{y(\text{metres})}$. Thus, the total RMS error (in metres) would be:

$$\sigma_{\text{model}} = \sqrt{\sigma_{x(\text{metres})}^2 + \sigma_{y(\text{metres})}^2}.$$

It is thus possible to obtain estimates of the actual misregistration error in temporal data sets.

DATA SOURCES

Four P-format MSS data sets were used in this study, as defined in Table 1. All scenes included the New Orleans, Louisiana, metropolitan area (Landsat-4 worldwide reference system Path 22, Row 39) as well as portions of the Mississippi Gulf Coast. A diversity of land covers/land use was present, including cropland/pasture, dryland, forest, forested wetlands, marsh, water bodies, small towns, rivers, etc.

Landsat-2 MSS data for 1980 served as the base data set throughout the study, as they were already in house. All other data were used as map data sets and were independently registered to the 1980 data set.

ANALYSIS AND RESULTS

Actual analysis began with the temporal registration of the 1981 Landsat-2 data set to the 1980 Landsat-2 data set. The results obtained (Table 2) were typical of temporal registrations obtained in the past at NASA/NSTL/ERL using Landsat 1, 2, or 3 data sets (Seyfarth and Cook 1981). Subsequent analysis of the errors on an OA-point-by-OA-point basis showed no trends in the registration errors in terms of direction of error or magnitude. Thus, a particularly "uniform" fit was achieved.

The 1982 Landsat-4 MSS data set was received in January 1983, and an independent temporal registration was produced. The results (Table 2) indicated a substantial pixel component error (almost twice the error obtained in the Landsat-2 to Landsat-2 registration). The model error (estimate of the actual misregistration) also demonstrated a considerable degeneration, undoubtedly the result of the large pixel error. When examined on an OA-point-by-OA-point basis, however, a sinusoidal pattern was observed when the magnitude of the pixel errors was plotted versus pixel location (Figure 1). Because the position of the MSS scan mirror is directly related to the pixel location, this result suggested that the coefficients used to model the scan mirror motion were not correct. No detectable pattern was noted for scan line errors.

In late January 1983, just before the MSS system onboard Landsat-4 was turned over to NOAA, corrections were made to the scan mirror coefficients

TABLE 2. RESULTS OBTAINED FOR THE REGISTRATION OF THREE SCENES OF LANDSAT P-FORMAT MSS DATA TO A COMMON BASE DATA SET

COMPONENT ERROR	LANDSAT-2 (1981)	LANDSAT-4 (1982)	LANDSAT-4 (1983)
Pixel Error	20.42 metres	40.32 metres	20.04 metres
Scan line Error	26.70 metres	26.95 metres	26.65 metres
Model RMS Error	33.61 metres(74)*	48.50 metres(67)*	33.35 metres(72)*

* Values enclosed in parentheses represent the number of OA points used to generate the corresponding statistic.

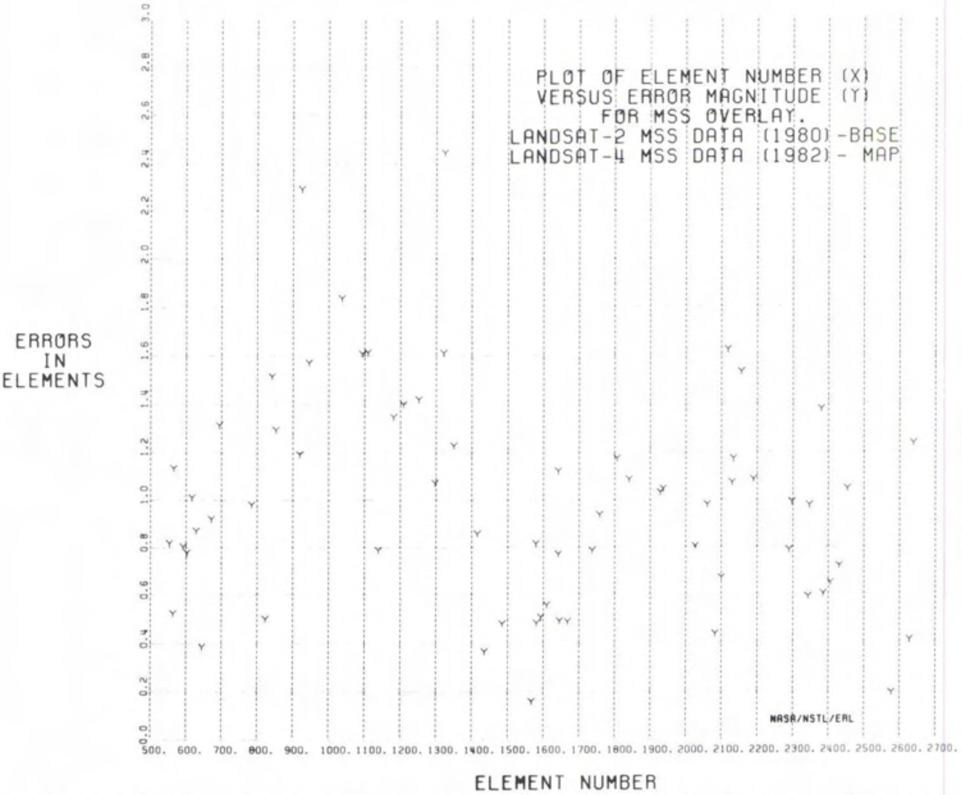

FIG. 1. Plot of Element Number (x) Versus Error Magnitude (y) for MSS Overlay. Landsat-2 MSS Data (1980)—Base; Landsat-4 MSS Data (1982)—Map.

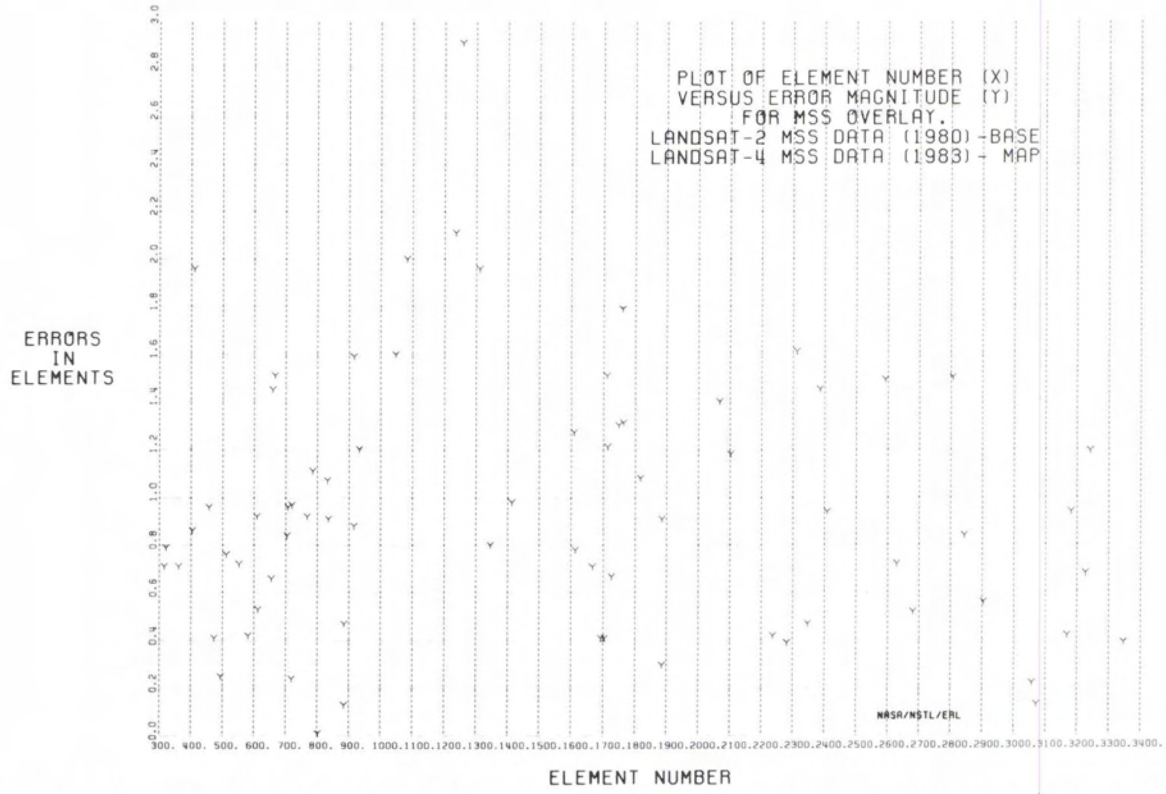

FIG. 2. Plot of Element Number (x) Versus Error Magnitude (y) for MSS Overlay. Landsat-2 MSS Data (1980)—Base; Landsat-4 MSS Data (1983)—Map.

used in the Goddard Space Flight Center's ground processing software associated with the Landsat-4 MSS system (Beyer, 1983). The impact of this change can be seen in Table 2. The 1983 data set was collected and processed after the new coefficients were incorporated into the software. As can be seen (Table 2), the pixel component error has been reduced considerably and is now at the same level as the Landsat-2 only temporal registration. The scan line component seems to have been unaffected, and remains nearly constant for all of the temporal registrations produced, showing no discernible trends in either magnitude or direction (Figure 2).

In order to determine the significance of the changes noted, F-tests were conducted on the model RMS errors. The results indicated that, at the 10 percent level of confidence, the temporal registration using 1982 Landsat-4 MSS data (erroneous scan mirror coefficients) was significantly different from each of the two other temporal registrations. The results based on the use of the 1983 Landsat-4 MSS data (corrected coefficients) were not significantly different from those obtained using the 1981 Landsat-2 MSS data. While the results reported in this document were obtained using the NASA/NSTL/ Earth Resources Laboratory software, it is felt that similar results would arise from other registration systems as well.

CONCLUSIONS

It has been demonstrated that temporal registration of Landsat-4 MSS P-format digital data with historical data obtained by Landsat-2 can be performed to a degree of precision equal to that obtained when using Landsat-2 data as both the base and map data sets. Landsat-4 MSS data collected between July 1982 and February 1983 should be used with caution, because scan mirror motion coefficients were not optimum and use of the data may produce less than desirable results.

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