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Corrected Landsat Images Using a Small Computer

Landsat computer-compatible tapes were converted to scene-corrected and map-corrected images.

ABSTRACT: *Experience has shown that large computer facilities are not necessarily a prerequisite for converting Landsat computer-compatible tapes to scene-corrected and map-corrected images. A technique is discussed in which these tasks are accomplished on a small computer with 16,000 words of magnetic core storage and two disk storage units.*

INTRODUCTION

USERS OF LANDSAT DATA have a choice of a set of four NASA-produced black-and-white images, a color composite, or a set of computer-compatible tapes (CCT's) for each scene. The CCT's offer at least two advantages not offered by the images. First, the data on the CCT's represent primary data, whereas the images are a secondary product in which the process of reproduction inevitably results in degradation of the primary. Second, the CCT's contain all the numerical data for each of the Landsat multispectral scanner (MSS) bands recorded in a format suitable for automated data processing.

Experience at the U. S. Army Engineer Waterways Experiment Station (WES) has shown that CCT data can be processed on a small computer having only 16,000 words of magnetic core storage and two disk storage units to produce both scene-corrected and map-corrected images, i.e., images that have been corrected to achieve geometric accordance with maps regardless of the map projection. This paper presents the techniques that are used.

LANDSAT COMPUTER-COMPATIBLE TAPE DATA

An understanding of the informational content of the Landsat CCT's is a necessary precursor to an understanding of how CCT's can be processed to produce scene-corrected and map-corrected images.

The information recorded on the CCT's can best be described by considering the measurement sequence of the MSS. (The following is a simplification of the actual measurement sequence for the sake of clarity.) The MSS has an instantaneous field-of-view that encompasses a spot (pixel) on the terrain surface about 57 by 79 m in size (approximately 0.45 ha) at the nadir point. A scanning mirror causes the instantaneous field-of-view to be deflected along lines normal to the orbital path of the satellite while successive measurements are made at regular intervals along each scan line. In this manner, the MSS measures the spectral reflectance of 3240 contiguous pixels along each scan line. A total of 2340 scan lines defines a Landsat scene covering an area on the ground approximately 185 by 185 km (100 by 100 nautical miles).[1,2] Thus, each 34,225-km^2 area of the terrain surface is described by 7,581,600 pixels, each of which is characterized by a value for each spectral band.

Values for each pixel are recorded on the CCT in the order taken, so that the location of each pixel with respect to all other pixels in the scene is retained as long as the location of the pixel value within the series of values recorded on the CCT remains unchanged. This can be more clearly envisioned by mentally placing a uniform grid comprised of rectangular cells over an area on the ground. Each cell in the grid corresponds to a pixel. As the instantaneous field

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of view of the MSS is deflected along a scan line (x-direction), reflectance is measured and recorded for each cell in the first row. After the reflectance of the last cell in the first row has been measured and recorded, an inter-record gap code is automatically recorded on the CCT to signify that recordings for the next row of cells are about to begin. This process is repeated until the reflectance of the last cell in the last row of the grid has been measured and recorded. An end-of-file code is then recorded automatically on the CCT to conclude the digitizing process and indicate that all data for one scene have been recorded.

By this process, the reflectance values measured for each cell in the grid are recorded. At the same time, the location of each cell with respect to all other cells in the grid is implied by the locations of the recorded values on the CCT. The value of any cell (pixel) can be located on the CCT in terms of its x-y position simply by counting interrecord gap codes to find the desired row (y-value) and counting the pixel values to find the desired position (x-value). Data recorded in this manner are commonly referred to as being in image format and can be converted to an image on photographic film.

Method of Converting CCT's to Images on Photographic Film

WES personnel convert CCT's to images on photographic film with an incremental film reader/writer (Figure 1). As long as both the pixel values and the spatial position of the values on the CCT's are unchanged, the resulting image is, in effect, a photographic replica of an area on the terrain surface as it appears to the Landsat MSS.

The film reader/writer is an electromechanical photograph scanning and film-writing system designed to accommodate photographs of up to 22.9 by 22.9 cm in size. The instrument can operate in either of two modes—an input or scanning mode, or an output or writing mode. The writing mode is used to convert data on CCT's to images in photographic form. For this mode of operation, the instrument is equipped with a rotating drum and an optical system consisting of a light-emitting diode, a selectable aperture, and a lens system that focuses a spot of light from the diode onto the perimeter of the drum. The drum is housed in a light-tight enclosure, which is moved to a photographic darkroom for film loading and unloading. A piece of film is clamped to the outside of the drum for exposure.

The film can be exposed using 0.0125-, 0.025-, or 0.05-mm spots of light from the diode. The raster interval and spot size are selectable. As the drum rotates, the carriage supporting the optical system is moved forward one step per drum revolution in the axial direction at the selected raster interval until the total area of the film or the area of interest has been exposed. The use of high-speed film permits very short exposure times and results in a recording rate of up to 60,000 exposures per second.

The intensity of light from the diode is modulated incrementally in proportion to the pixel values recorded on a CCT. Thus, as the drum of the film reader/writer rotates, a spot is exposed on the film for each pixel value in a scan line (row). When an inter-record gap code occurs, the diode is extinguished until the drum revolution is completed and the carriage for the optical system has moved forward one increment. Exposure of the next row of spots then begins. This process is repeated until the end-of-file code occurs on the CCT.

The film reader/writer is controlled by a digital minicomputer so that real-time manipulation of the CCT values can be used to

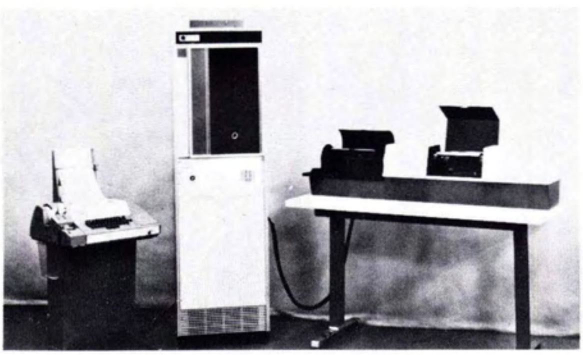


Fig. 1. Film reader/writer.

enhance image contrast as well as to produce a number of photographic effects.

Procedure for Producing Scene-Corrected Images

Scene-corrected images are produced by correcting the CCT data for errors due to pixel shape and skew.

PIXEL SHAPE CORRECTIONS

A photographic image written on film by the film reader/writer is comprised of an orthogonal array of *square* spots, each of which is recorded on the film as a shade of gray proportional in optical density to the corresponding pixel value recorded on the CCT. Since the MSS pixel has a width-to-length ratio of approximately 1:1.38, the discrepancy between the shape of the film reader/writer pixel and the MSS pixel must be corrected. To do this, a copy is made of the CCT with the pixel values of every third and every twentieth scan line duplicated (Figure 2). This procedure increases the number of scan lines of data on the CCT from 2340 to 3237. An image produced from the resulting tape in this way is "stretched" to closely conform geometrically to the area covered on the terrain surface by a Landsat scene.

SKEW CORRECTIONS

Skew results because approximately 25 seconds are required for Landsat to traverse from the northern extremity to the southern extremity of a scene. During this time the rotation of the earth carries the surface eastward a finite amount. At the latitude of the southern United States where the WES is located, the surface moves eastward with respect to the satellite orbital path one pixel width (57 m) in about 0.124 sec. In the time that it takes the surface to move eastward the width of one pixel, the satellite has advanced southward along its orbital path a distance equivalent to about 11.6 scan lines. This systematic error can be corrected to the accuracy required in most instances by offsetting each successive group of 12 scan lines to the westward one pixel width, as shown in Figure 3. A total of 260 false pixels are inserted on the CCT either at the beginning or at the end of each scan line to bring the digital array back into a rectangular array. The re-

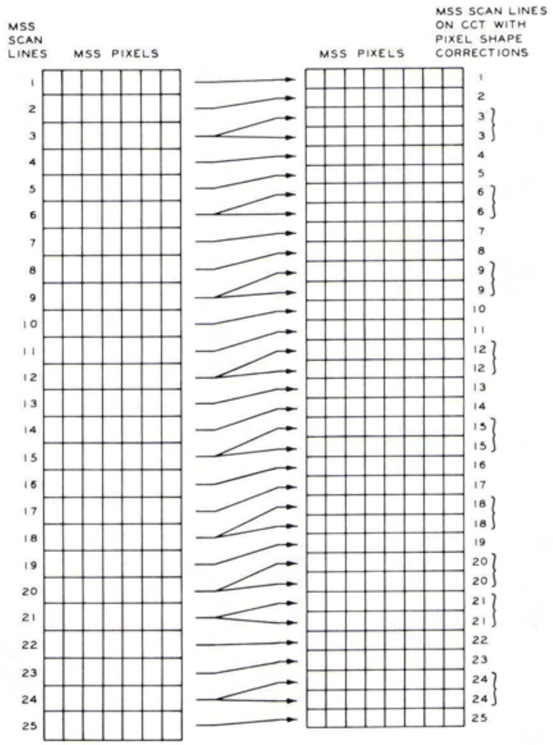


Fig 2. Correcting film reader/writer pixel shapes by "stretching".

sulting array contains 3500 pixels per scan line.

The result of this process is barely perceptible on the resulting film because of the small pixel size (0.05 mm) used to expose the film, but is nevertheless effective for approximately correcting for skew.

COMPARISON OF WES AND NASA SCENE-CORRECTED IMAGES

Figure 4 shows that WES scene-corrected images are comparable in most respects to the scene-corrected images produced by NASA. The major difference is that the scale of this WES-produced image is 1:1,152,500 rather than 1:1,000,000.

PROCEDURE FOR PRODUCING MAP-CORRECTED IMAGES

As long as the location of each value recorded on a CCT with respect to all other recorded values remains unchanged, the geometric integrity of the image produced from the CCT will be retained. Conversely, an image can be geometrically changed by systematically changing the relative position of pixel values recorded on CCT's.

The technique for doing this is based on the results of a research study by K. W. Wong concerned with the geometric and cartographic accuracy of MSS images.[3] In this study, geometric distortions were modeled with a pair of 20-term polynomials, the general form of which is—

$$\begin{aligned} x_{\text{calibrated}} = x &+ b_1 + b_2x + b_3y + b_4xy + b_5x^2 \\ &+ b_6y^2 + b_7x^2y + b_8y^2x + b_9x^3 \\ &+ b_{10}y^3 + b_{11}x^3y + b_{12}y^3x + b_{13}x^4 \\ &+ b_{14}y^4 + b_{15}x^2y^2 + b_{16}x^3y^2 \\ &+ b_{17}y^3x^2 + b_{18}x^5 + b_{19}y^5 + b_{20}x^3y^3 \end{aligned}$$

$$\begin{aligned} y_{\text{calibrated}} = y &+ c_1 + c_2x + c_3y + c_4xy + c_5x^2 \\ &+ c_6x^2 + c_7x^2y + c_8y^2x + c_9x^3 + \ldots \\ &+ c_{20}x^3y^3 \end{aligned}$$

where x and y are measured coordinates of a transfer point on the image, and b's and c's are coefficients of the x and y equations, respectively.

A computer program (POLY20) was developed by Wong to determine the coeffi-

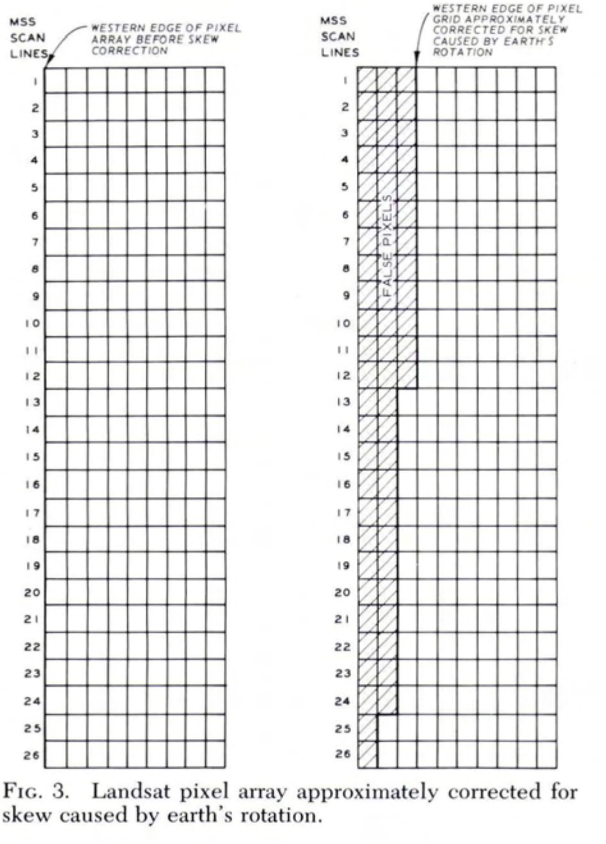


FIG. 3. Landsat pixel array approximately corrected for skew caused by earth's rotation.

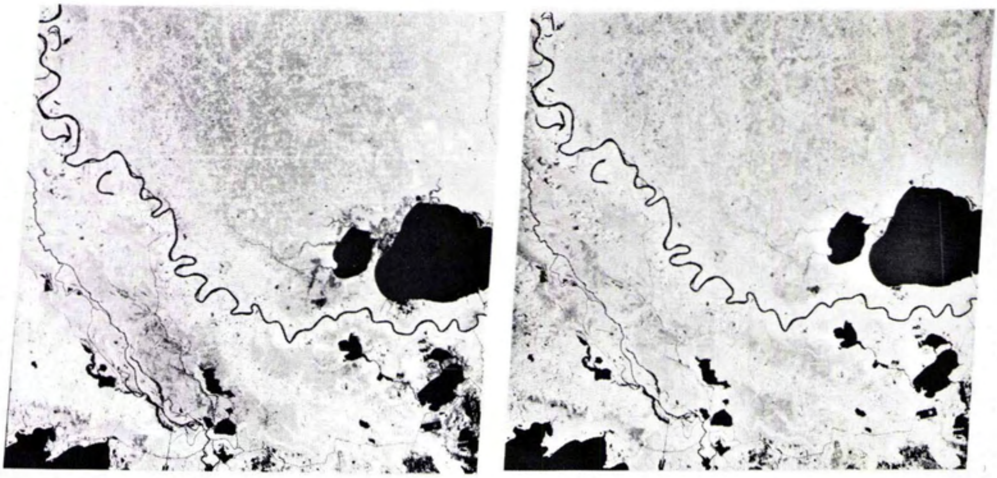


FIG. 4. Comparison of scene-corrected images.

cients of a best-fitting polynomial for the x and y coordinates separately by the method of simultaneous least-squares adjustment, the x and y translation errors (*AO* and *BO*, respectively), and rotational error (θ). (Reference 3 documents this program and includes a complete computer program listing.) One or more terms of the polynomials can be held to zero in a solution, and the programs also can compute an estimate of the standard errors of the computed coefficients. Thus, the program can be used to model distortions with various degrees of polynomials; and from the standard errors of the computed coefficients, the insignificant terms in the polynomials can be identified in the data output. Moreover, measurements for several Landsat scenes can be used in a simultaneous solution to determine the one pair of best-fitting polynomials for a number of successive scenes.

Two MSS scenes were analyzed by Wong with the program POLY20. Transfer points, including highway intersections and water features, were identified in the scenes and on available 1:24,000-scale U. S. Geological Survey maps, and the coordinates of these points were then measured. Program POLY20 was then used to model the distortions by using polynomials of various degrees. The results show that the root-mean-square distortion vectors in bulk MSS imagery may range from ± 150 to ± 350 m. However, the distortion is highly systematic, and by using four or more transfer points, an MSS image can be corrected to meet the National Map Accuracy Standard requirement for mapping at 1:500,000 scale.(For maps at this scale, the standard requires that not more than 10 percent of all points tested shall be in error by more than 0.5 mm.) An accuracy of ± 55 m can be achieved by correction of each MSS scene with 25 to 30 transfer points.

To adapt Wong's equations for transforming the coordinates of transfer points in a Landsat scene into a calibrated system such as a map, an imaginary grid is assumed. This grid contains the 2340 scan lines with 3240 pixels per scan line corresponding to a Landsat scene, plus an additional 897 scan lines and 260 pixels per scan that result from pixel shape and skew corrections. The grid contains imaginary pixels each of which has an identifiable x-y location in the grid. The problem is to find in the Landsat CCT data (which for purposes of this discussion is considered as an array of pixels in a distorted, translated, and rotated grid) the address of the reflectance value to be placed at each location in the imaginary (undistorted) grid. To do this, two pairs of simultaneous equations are solved. The first pair of equations is:

$$x_r = a_1x + b_1y + c_1 + x \quad (1)$$

$$y_r = a_2x + b_2y + c_2 + y \quad (2)$$

where

x_r, y_r = coordinates of pixels in the undistorted, untranslated, unrotated grid.

$a_1, b_1, c_1, a_2, b_2, c_2$ = coefficients from solution of POLY20.

x, y = coordinates of reflectance values in the distortion-corrected grid.

Solution of these two equations simultaneously gives the address of the reflectance value in a distortion-corrected, but untranslated and unrotated grid. Translation errors in x and y and rotational errors must be corrected before the address of the proper reflectance value on the CCT can be determined. This is done by solving the second pair of simultaneous equations:

$$x = (x_i - AO) \cos \theta + (y_i - BO) \sin \theta \quad (3)$$

$$y = -(x_i - AO) \sin \theta + (y_i - BO) \cos \theta \quad (4)$$

where

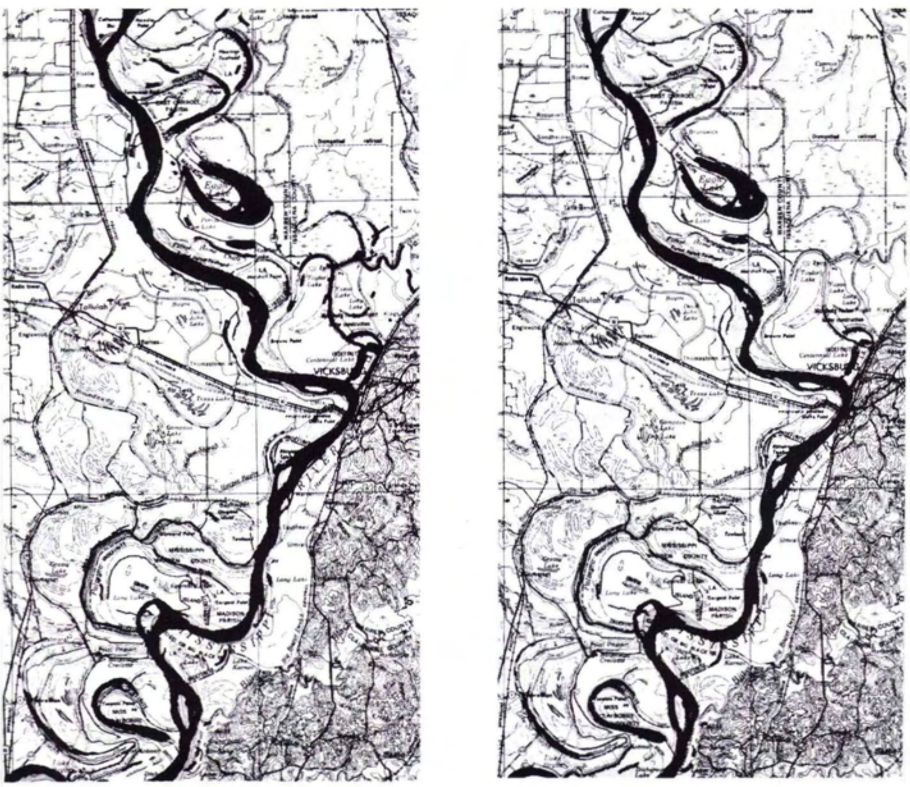
x, y = coordinates of reflectance values in the distortion-corrected grid (from solution of Equations 1 and 2 above).

x_i, y_i = location of reflectance value on Landsat CCT to be put at location x_r, y_r in imaginary grid.

AO, BO, θ = coefficients from solution of POLY20.

Equations 1 to 4 are used in the following way. The address of the first pixel in the first row of pixels in the imaginary (undistorted) grid (1,1) is substituted for x_r, y_r in Equations 1 and 2. Values for x and y from solution of Equations 1 and 2 are used in Equations 3 and 4 to solve for x_i, y_i. If x_i and y_i are not integers, the values are rounded to the nearest whole number to retain the integrity of the pixel values recorded on the CCT. This process is repeated for each pixel in each row of the imaginary grid, and the results are recorded on magnetic tape. When the process is completed, the magnetic tape contains the address on the Landsat CCT of each reflectance value to be placed in the imaginary grid.

This tape (hereinafter called the address tape) is then used as a director for a search of values on the Landsat CCT. The first address on the address tape is that of the reflectance value on the CCT to be placed at location 1,1 in the imaginary grid. The CCT is then searched again until the address of the reflectance value to be placed at 2,1 is found



Uncorrected Corrected

FIG. 5. Comparison of uncorrected and corrected overlays.

and the reflectance value at this address is placed at 2,1 in the imaginary grid. This process is repeated until values for the first row of pixels in the imaginary grid have been found. These values are then recorded on magnetic tape. Each successive row in the imaginary grid is filled with pixel values in this manner, and the results are recorded on magnetic tape. The resulting tape is in image format and therefore compatible with the film reader/writer.

Figure 5 presents a comparison of an uncorrected Landsat overlay showing a portion of the Mississippi River in the vicinity of Vicksburg, Mississippi, and the overlay geometrically corrected by this process. The coordinates of seven transfer points were used to calculate the correction coefficients and the translation and rotational errors. For clarity in this example, the CCT data were preprocessed so that only water bodies are shown on the overlays. The results are overlaid on Corps of Engineers map NH 15-12, which has a Universal Transverse Mercator projection.

In the uncorrected overlay, which was registered at the top of the map at the time this reproduction was made, the errors appear to be cumulative with increasing distance southward. In addition, a very slight rotational error becomes apparent with increasing distance southward. These errors do not appear in the corrected overlay.

The correction required to achieve geometric accordance of the Landsat scene and the map can be seen more clearly when the uncorrected and corrected overlays are positioned on a grid, as shown in Figure 6. Almost no correction was required at the north (upper) end of the scene, but the errors were cumulative, requiring correction in excess of 500 m near the south (lower) end of the scene.

Program POLY20 generates a list of residuals that provides an indication of the accuracy with which the coordinates of transfer points in a Landsat scene are adjusted to fit the coordinates of the transfer points on a map. Experience at the WES in processing 24 different scenes has shown that POLY20 typically will adjust the x and y coordinates of over 50 percent of the transfer points to an accuracy of two pixels or less (one pixel = 0.05 mm) and the location of over 10 percent of the transfer points to an accuracy of one pixel or less. Although the residuals provide a good indication of the accuracy provided by POLY20, they do not account for any errors that might result from errors in locating and measuring the coordinates of transfer points. Nor do they include any errors that might result from rounding solutions to the simultaneous equations used to find the location of pixel values that would fill the imaginary grid array.

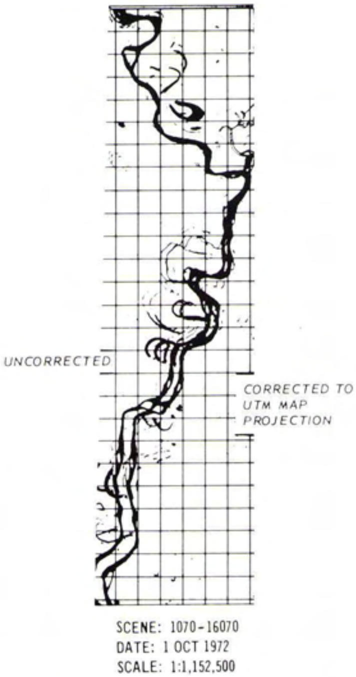


Fig. 6. Example of Landsat scene corrected to Universal Transverse Mercator map projection.

Summary

Experience at the WES has shown that both scene-corrected and map-corrected images can be produced from Landsat CCT's without the use of computing facilities with high-speed and large storage capacity. The technique discussed in the preceding paragraphs has been used repeatedly to convert CCT's to images on photographic film with a computer having only 16,000 words of magnetic core storage on two disk storage units.

References

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3. Wong, K. W., *A Computer Program Package for the Geometric Analysis of ERTS-1 Images*, Report UILU-ENG-74-2005, Mar 1974, University of Illinois at Urbana-Champaign, Urbana, Ill.