LARS Technical Report 081777

TECHNIQUES FOR ESTIMATING SCALES AND AREAS FOR LANDSAT DATA

Pierre-Marie Adrien
Soil Scientist, Project Analysis Department, Inter-American Development Bank and Visiting Scientist at LARS

Vern Vanderbilt
Post-doctoral Fellow, LARS

Laboratory for Applications of Remote Sensing
Purdue University
W. Lafayette, Indiana 47907

1 Sepember 1977

ABSTRACT

Landsat multispectral scanner (MSS) data is available from the Eros Data Center, Sioux Falls, South Dakota principally in two formats, false color composite photographs and computer compatible tapes. Basically, the data are analyzed either through visual interpretation (using, for example, the Bausch and Lomb Zoom Transfer Scope) or through application of digital techniques which process the tapes on digital computers.

Because obtaining the Landsat imagery at one particular scale is often crucial to successful completion of an analysis project, techniques have been developed - both optical and digital - for dimensionally scaling the imagery. When optical techniques are employed, the scale of the photographic image is changed by expanding or reducing the size of each pixel using, for example, the Zoom Transfer Scope. This process is contrasted with the digital image analysis technique in which pixels are often eliminated to obtain a specific scale.

This technical report describes mathematically the scaling processes used in both the optical and digital techniques. The following numerical properties of each method are summarized as a function of scale in two tables: Landsat pixels/square centimeter of image, surface area represented by each square centimeter of image (in hectares, acres, and square kilometers), number of pixels represented by each displayed data point, and surface area represented by each displayed data point (in hectares, acres, and square kilometers).

LANDSAT DATA

Since the launch of Landsat-1 in July 1972, the vast flow of data produced by the earth orbiting resources satellites and stored at the EROS Data Center, Sioux Falls, South Dakota have been mostly transmitted to scientists and members of the user community in two formats. One is the standard false color composite photographs which are available in three scales - 1:250,000; 1:500,000 and 1:1,000,000. The second is the computer compatible tapes (CCT's) from which the false color composites and other photographic products can be obtained.

The data recorded in analog form by Landsat multispectral scanner is rapidly digitized on board the satellite before being telemetered to ground receiving stations in Brazil, Canada, Italy and the United States. Radiation is sensed simultaneously by an array of six detectors in each of the four MSS spectral bands from 0.5 to 1.1 micrometers. The detectors' outputs are sampled, encoded to six bits and formatted into a continuous data stream of 15 megabits per second. The data gathering process is continuous and covers on the earth's surface a swath 185km wide. For ease of handling, EROS distributes the data mainly as false color composites and CCT's in frames or images which correspond to surface measurements equivalent to 185km by 185km or 34,225 square kilometers. These measurements are equal to 3,422,500 hectares or 8,457,182 acres.

The sampling techniques used to digitize Landsat data produce resolution elements or picture elements commonly referred to as pixels. A pixel is approximately rectangular in shape and represents surface measurements approximately equal to 79 meters (length) by 57 meters (width) or 0.45 hectare (1.12 acre). Although the length and width of Landsat swath are each 185km, the number of pixels per column (length) and line (width) is unevenly distributed. A column contains 2340 pixels and a line includes either 3232 pixels (Landsat-1) or 3256 (Landsat-2). In every Landsat frame or image, there are about 7.5 million pixels per MSS band or 30 million quantitative reflectance values which are recorded in 25 seconds.

DATA ANALYSIS

Landsat data are basically analyzed either through visual interpretation techniques or through application of digital techniques.

Visual analysis includes the use of such equipment as Bausch and Lomb Zoom Transfer Scope, Richards light table, mirror stereoscopes and others while digital analysis refers to the use of computers like the IBM 370/148 and others to process the CCT's (standard 0.5 inch or 1.27 centimeter polyester base magnetic tapes).

When visual analysis techniques are used, the scale of the photographic image is changed by expanding or reducing the size of each pixel using, for example, a zoom transfer scope. This process is contrasted with the digital image analysis technique in which pixels are often eliminated to obtain a specific scale. Table 1 lists the number of pixels and surface area per square centimeter of photographic image at various scales.

While the Landsat photographic products of the EROS Data Center are available in three scales, the scale of the Landsat images encoded on the CCT's is not fixed; instead, the scale of an image generated from a CCT depends upon (1) the geometric characteristics of the computer peripheral device (e.g. line printers and the Varian plotter at LARS) used to display the digital image, (2) whether or not the image encoded on the tape has been corrected for various geometric scale distortions (such geometric corrections, routinely performed at LARS, are discussed in Anuta, 1973) and (3) the scale (a) specified by the analyst during the geometric correction process and/or (b) selected by the analyst during use of the LARSYS processors.

Let us discuss the geometric characteristics of the line printer using, as examples, two sets of digital data that have and have not been geometrically corrected. At LARS the line printer output has 10 columns and 8 lines per inch, respectively. Therefore, for geometrically uncorrected digital data the length and width of the digital image displayed on the line printer are

$$(2340 \text{ pixels}) \times (1 \text{ inch}/8 \text{ pixels}) = 292.5 \text{ inches in length}$$
$$(3232 \text{ pixels})^{*} \times (1 \text{ inch}/10 \text{ pixels}) = 323.2 \text{ inches in width}$$

(*Landsat-1 has 3232 pixels/line while Landsat-2 has 3256.) and the scale of the image is different in length and width:

$$\frac{(185 \text{ km})(100{,}000 \text{ cm/km})}{(292.5 \text{ inches})(2.54 \text{ cm/in})} = 24{,}901 \text{ (length)}$$

$$\frac{(185 \text{ km})(100{,}000 \text{ cm/km})}{(323.2 \text{ inches})(2.54 \text{ cm/in})} = 22{,}535 \text{ (width)}$$

or

1:24,901 (length)
1:22,535 (1:22,369 for Landsat-2) (width)

When geometric correction procedures are applied, the digital data are manipulated so that the scale of the image produced (by the line printer for this example) is that required by the analyst. As an example, for analyses involving topographic maps one scale often selected is 1:24,000, and, unlike for non-geometrically corrected data, the scale for a geometrically corrected image is the same - 1:24,000 - in both directions.

The computer algorithms at LARS for geometric correction of Landsat digital data use the nearest neighbor rule (Anuta, 1973). The rule assigns to each pixel location in the geometrically corrected image, that location's nearest neighbor from the uncorrected image. As implemented at LARS, the geometric correction process involves geometric transformations and only infrequently, radiometric transformations (for example, cubic interpolations).

The nearest neighbor algorithm, when used to obtain images with scales smaller than 1:25,000 (i.e. 1:50,000, 1:1,000,000, etc.), often eliminates significant numbers of pixels from the data set. For example, the algorithm eliminates approximately three out of every four pixels to produce an image on the line printer at a scale of 1:50,000. The fact must be emphasized that these eliminated data values are not in any way averaged to obtain the data points displayed in the geometrically corrected data at the new, smaller scale nor will the eliminated pixels appear in any LARSYS analysis involving the geometrically corrected data at the smaller scale.

Even after the digital data has been geometrically corrected to the required scale, the data analyst may further change the scale of the data using options in the LARSYS processors. These options allow the analyst to include only every nth line and/or column in the analysis and to exclude from analysis the remaining lines and/or columns. The factor, n, is an integer.

In Summary then, for image scales smaller than 1:25,000 for line printer data large numbers of pixels are deleted from the non-geometrically corrected digital image during the geombtric correction process at LARS and also from the LARS geometrically corrected digital data during LARSYS analyses involving certain processor options. Table 2 lists the number of pixels in the non-geometically corrected digial image and ground areas represented by each displayed data point at different scales.

PROBLEMS RELATED TO SCALE CALCULATION

Because of the quantized nature of the line/column elimination technique employed in the LARSYS processors, the scale of a Landsat image displayed on a line printer will often not precisely equal a desired scale. Thus, if obtaining a particular scale in the table requires that exactly, for example, 0.495 of the lines in an image be eliminated, then the desired scale may be closely approximated by eliminating one of every 2 lines. The process is not exact because the decimal 0.5 does not equal 0.495.

A second feature of the line/column elimination technique is that the scale at any specific location in the product image may vary from the desired scale. This is because only an integer number of lines/columns can be eliminated in the image. Even so, the average scale of such an image can be made to closely approximate the desired scale.

While possibly theoretically important, these idiosyncracies of the line/column elimination technique generally deserve no attention during the analysis of the digital data.

SCALE CALCULATIONS: OPTICAL ENLARGEMENT

The mathematical formulas for the OPTICAL enlargement (or reduction) of Landsat-1 images entail the following calculations:

$$\frac{185 \text{ km per column}}{2340 \text{ pixels per column}} = 79.060 \text{ meters per pixel (length)}$$

$$\frac{185 \text{ km per line}}{3232 \text{ pixels per line}^{*}} = 57.240 \text{ meters per pixel (width)}$$
(or 56.818 for Landsat-2)

*Note that Landsat-1 has 3232 pixels/line while Landsat-2 has 3256.

area of pixel = length X width

= (79.060)(57.240)

= .45254 hectares per pixel
(or .44920 for Landsat-2)

= 1.11825 acres per pixel
(or 1.11001 for Landsat-2)

From conversion tables we find that 2.471054×10^{-8} acres = 1 square centimeter. Hence, for a scale of 1:25,000,

$$\left(\frac{1 \text{ pixel}}{1.11825 \text{ acre}}\right)\left(\frac{2.471054 \times 10^{-8} \text{ acres}}{1 \text{ cm}^2 \text{ on ground}}\right)\left(\frac{(25 \times 10^3)^2 \text{ cm}^2 \text{ on ground}}{1 \text{ cm}^2 \text{ on image}}\right)$$

$$= 13.8109 \text{ pixels per cm}^2 \text{ on image}$$
(or 13.9135 for Landsat-2)

there are 13.8109 (13.9135) pixels per square cm of Landsat-1 (Landsat-2) image. And, again for a scale of 1:25,000,

$$\left(\frac{(25 \times 10^3)^2 \text{ cm}^2 \text{ on ground}}{1 \text{ cm}^2 \text{ on image}}\right)\left(\frac{1 \text{ hectare on ground}}{10^8 \text{ cm}^2 \text{ on ground}}\right)$$

$$= 6.25 \text{ hectare per cm}^2 \text{ of image.}$$

There are 6.25 hectares of ground area per square centimeter of image area. Or, converting hectares to acres,

$$\left(\frac{6.25 \text{ hectare}}{\text{cm}^2 \text{ of image}}\right)\left(\frac{2.471054 \text{ acres}}{1 \text{ hectare}}\right) = \frac{15.4441 \text{ acres}}{\text{cm}^2 \text{ of image}}$$

There are 15.4441 acres of ground area per square centimeter of image area. Area values (listed in Table 1) for other scales are obtained using the formulas:

number of pixels at a scale of n $= \left(\frac{n}{n_1}\right)^2 \left(\frac{13.8109^{*} \text{ pixels}}{\text{cm}^2 \text{ of image}}\right)$

number of hectares of area per cm^2 of image at a scale of n $= \left(\frac{n}{n_1}\right)^2 \left(\frac{6.2500 \text{ hectares}}{\text{cm}^2 \text{ of image}}\right)$

number of acres of area per cm^2 of image at a scale of n $= \left(\frac{n}{n_1}\right)^2 \left(\frac{15.4441 \text{ acres}}{\text{cm}^2 \text{ of image}}\right)$

number of square km of area per cm of image at a scale of n $= \left(\frac{n}{n_1}\right)^2 \left(\frac{0.0625 \text{ square km}}{\text{cm}^2 \text{ of image}}\right)$

*13.9135 for Landsat-2.
where n = desired scale (i.e. 50,000, etc.)
n_1 = 25,000

SCALE CALCULATION: DIGITAL ENLARGEMENT

DIGITAL manipulation of the scale of Landsat data involves several additional formulas. First, it will be assumed that all data is to be displayed on the line printer. For geometrically uncorrected Landsat data the scale is not the same in both directions on the printer output. As discussed above, it is

1:24,901 (length)
1:22,535 (1:22,369 for Landsat-2) (width)

and the area of one pixel is

= 1.11824 acre (or 1.11001 for Landsat-2)

= 0.45254 hectare (or 0.44920 for Landsat-2)

For geometrically corrected data at a scale of 1:25,000, again displayed on the line printer, the area represented by each displayed data point is

$$\left(\frac{\text{25,000 inches on ground}}{\text{1 inch on printer image}}\right)\left(\frac{\text{1 inch on printer image}}{\text{8 displayed data points}}\right) = \frac{\text{260.42 feet on ground}}{\text{displayed data point}} \quad \text{(length)}$$

$$\left(\frac{\text{25,000 inches on ground}}{\text{1 inch on printer image}}\right)\left(\frac{\text{1 inch on printer image}}{\text{10 displayed data points}}\right) = \frac{\text{208.33 feet on ground}}{\text{displayed data point}} \quad \text{(width)}$$

Therefore, the area per displayed data point for a scale of 1:25,000 is

$$\text{(length)(width)} = (260.42)(208.33)$$

$$= 1.24549 \text{ acre}$$

$$= 0.50403 \text{ hectare}$$

For other image scale factors the area represented by each displayed data point is obtained using the formulas

$$\text{Area represented by each displayed data point in hectares} = \left(\frac{n}{n_1}\right)^2 (0.50403)$$

$$\text{Area represented by each displayed data point in acres} = \left(\frac{n}{n_1}\right)^2 (1.24549)$$

$$\text{Area represented by each displayed data point in square km} = \left(\frac{n}{n_1}\right)^2 (0.0050403)$$

where n is the new scale factor (i.e. 50,000, 75,000, etc.)
n_1 is 25,000.

The number of pixels represented by each displayed data point is calculated using the formula

$$\text{no. of pixels represented by each displayed data point} = \frac{\text{area represented by each displayed data point at desired scale}}{\text{area represented by each displayed data point for geometrically uncorrected data}}$$

For example, for a scale of 1:25,000

$$\text{No. of pixels represented by each displayed data point} = \frac{0.50403 \text{ hectare}}{0.45254^{*} \text{ hectare}} = 1.11$$

*0.44920 for Landsat-2

CONCLUSIONS

Two methods, commonly used to change the scale of Landsat imagery, have been described in the text. While employing radically different techniques, the methods, one optical and the other digital, invite mathematical description of their salient features such as scale, pixel size, etc. The discussions in the text and the tables attempt to provide those persons working with Landsat data a way of determing these features.

How universal are these methods? The optical techniques described in the text (and used to establish Table 1) are widely employed in remote sensing and in other fields. However, the computer techniques described in the text and employed at LARS to manipulate digital Landsat image data, while not unique to LARS, are by no means universally used elsewhere. Therefore, the results in Table 2 apply specifically to digital Landsat data which has been geometrically corrected at LARS.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to Paul Anuta, Barbara Davis, Dave Freeman, Bill Shelley, and Chuck Smith for their constructive suggestions.

REFERENCES

Data Users Handbook, Document No: 76SDS4258 (NASA, Houston, revised edition, 1976).

Lintz, J. and Simonett, D. S., 1976. "Remote Sensing of Environment." Addison-Wesley Publishing Co., Inc.

Manual of Remote Sensing, 1975. American Society of Photogrammetry

LARS Minicourses: "Landsat: An Earth Resources Satellite System" and "Photographic Sensors." Purdue University.

Anuta, P. E., 1973. "Geometric Correction of ERTS-1 Digital Multispectral Scanner Data." LARS Information Note 103073, Purdue University, W. Lafayette, Indiana.

Table 1. Relationship between scale and area of Landsat photographic images enlarged or reduced using optical devices such as a Zoom Transfer scope.

scale	pixels per cm^2 of image	surface area represented by each cm^2 of image		
	Landsat-1 or (Landsat-2)	hectare	acre	square km
1:15,840•	5.5 (5.6)	2.5	6.2	0.025
1:20,000•	8.8 (8.9)	4.0	9.9	0.040
1:24,000••	12.7 (12.8)	5.8	14.2	0.058
1:25,000	13.8109 (13.9135)	6.2500	15.4441	0.0625
1:50,000	55 (56)	25	62	0.25
1:62,500•••	86 (87)	39	97	0.39
1:75,000	124 (125)	56	139	0.56
1:100,000	221 (223)	100	247	1.0
1:125,000	345 (348)	156	386	1.56
1:150,000	497 (501)	225	556	2.25
1:175,000	677 (682)	306	757	3.06
1:200,000	884 (890)	400	988	4.00
1:250,000	1,381 (1,391)	625	1544	6.25
1:500,000	5,524 (5,565)	2,500	6,178	25.00
1:1,000,000	22,097 (22,262)	10,000	24,711	100.00

•scales often used for soil survey maps, soil conservation service, United States Department of Agriculture.
••Scale, 7.5 minute topographic maps, United States Geological Survey.
•••Scale, 15 minute topographic maps, United States Geological Survey.

Table 2. Relationships between scale and area of Landsat digital images enlarged or reduced using digital computer algorithms developed at LARS. The image is displayed on a line printer which prints 8 lines per inch.

scale	no. of pixels represented by each displayed data point for Landsat-1 or (Landsat-2)	surface area represented by each displayed data point		
		hectares	acres	square km
non-geometrically corrected Landsat data:				
1:24,901 (length)				
1:22,535 (1:22,369, Landsat-2) (width)				
Landsat-1:	1.00	0.45254	1.1183	0.0045
(Landsat-2):	(1.00)	(0.44920)	(1.1100)	(0.0045)
LARS geometrically corrected Landsat data:				
1:15,840*	0.45 (0.45)	0.202	0.50	0.0020
1:20,000*	0.71 (0.72)	0.323	0.80	0.0032
1:24,000**	1.03 (1.03)	0.465	1.15	0.0046
1:25,000	1.11 (1.12)	0.50403	1.2455	0.0050
1:50,000	4.46 (4.49)	2.02	5.0	0.0200
1:62,500***	6.96 (7.01)	3.15	7.8	0.032
1:75,000	10.0 (10.1)	4.54	11.2	0.045
1:100,000	17.8 (18.0)	8.06	19.9	0.081
1:125,000	27.8 (28.1)	12.6	31.1	0.126
1:150,000	40.1 (40.4)	18.1	44.8	0.181
1:175,000	54.6 (55.0)	24.7	61.0	0.247
1:200,000	71.3 (71.8)	32.3	79.7	0.323
1:250,000	111 (112)	50.4	125	0.504
1:500,000	446 (449)	202	498	2.02
1:1,000,000	1782 (1795)	806	1993	8.06

*Scales often used for soil survey maps, Soil Conservation Service, United States Department of Agriculture.
**Scale, 7.5 minute topographic maps, United States Geological Survey.
***Scale, 15 minute topographic maps, United States Geological Survey.