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OVERALL EVALUATION OF ERTS-1 IMAGERY FOR CARTOGRAPHIC APPLICATION
(NASA #233)

Alden P. Colvocoresses
U.S. Geological Survey
1340 Old Chain Bridge Road
McLean, Virginia 22101

August 1973

Type II Progress Report for Period January 1, 1973 - July 1, 1973
(extended to August 1, 1973)

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Prepared for: Goddard Space Flight Center
Greenbelt, Maryland 20771

Publication authorized by the Director, U.S. Geological Survey

Type II Progress Report

ERTS-A

a. Title: Overall Evaluation of ERTS-1 Imagery for Cartographic Application

ERTS-A Proposal No: SR 233

b. GSFC ID No. of P.I.: IN 014

c. Problems:

By 1 July 73 practically all of the US was covered by MSS imagery suitable for cartographic purposes. Unfortunately no cartographic products in final form were produced for the following reasons.

- o Mosaics are required for standard quad forms and the density difference between images create objectionable photometric anomalies.
- o Mosaic production is currently limited to monochromatic processing whereas, to be fully effective, color rendition is required.
- o There are small but real discontinuities between images that complicate the laying of accurate ERTS mosaics.
- o The 1:250,000 scale at which most experiments were conducted is proving to be larger than is optimum for the lithographic reproduction of ERTS imagery.

d. Accomplishments and Plans:

Reports submitted with respect to ERTS experiment Nos. 116, 149, 150, 211 and 237 cover specific accomplishments in the cartographic field. The referred to EC memos also cover and summarize some of the accomplishments. The most significant accomplishment and plan stems around recent decisions to publish in color selected ERTS scenes in cartographic (gridded) form at 1:500,000 scale. The first such scene covers the Washington, D.C. area.

e. Scientific conclusions and results:

Significant scientific results may be summarized as follows:

- o A geodetic (UTM) grid can be fitted to MSS bulk images with a positional accuracy in the order of 50 meters (rms)
- o The MSS imagery as corrected and printed in bulk form is

in effect or a defined map projection. This projection, if optimized for cartographic presentation, will have distortions in the order of only 1 part in 10,000.

- The orbit of ERTS and image delineation of MSS imagery can be held by NASA so that predesignated scenes may be identified and used as a basis for a map series. This concept could reduce the time and cost of ERTS image map production many fold or compared to standard quadrangle format production.

f. Published articles and reports:

- "Progress in Cartography, EROS Program" (Colvocoresses and McEwen) Presented at the ERTS Symposium (NASA) of March 1973. (Copy attached)
- "The Cartographic and Scientific Application of ERTS-1 Imagery in Polar Regions" (Southard and MacDonald) Presented at Konstanz F.R.G., May, 1973. (Previously forwarded, Exp. #149)
- "Unique Characteristics of ERTS" (Colvocoresses) Presented at the ERTS Symposium (NASA) of March 1973. (Copy attached)
- Six Memorandums for Record designated EC-14 through 19 (Copies attached)

g. Recommendations:

- That MSS bulk imagery be cast on a simple Space Oblique Mercator projection rather than the semiperspective one used today.
- That orbital and processing controls be initiated that will insure repeatability of the ERTS scene to within $\pm$ 10 km of the designated nominal scene.
- That precision processing be reviewed.
- That all possible steps be taken towards definition of an operational ERTS type satellite system.

TECHNICAL REPORT STANDARD TITLE PAGE

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		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract During the period significant results of the cartographic investigations of ERTS were recorded in the form of technical memos and cover the following items:

- o Thin cloud penetration capability of ERTS MSS band 7 (EC-14)
- o Summary of advantages of ERTS over film return systems (EC-15) The matter was further developed into two formal papers. "Unique Characteristics of ERTS" and "Unique Cartographic Characteristics of ERTS."
- o Summary of the status and cartographic problems of scene corrected (precision processed) ERTS images (EC-16)
- o Status of positional referencing capabilities of ERTS imagery (EC-17)
- o Map projection of the bulk (system corrected) ERTS MSS image (EC-18)
- o Status of the ERTS image format as the basis for a map series (EC-19)

17. Key Words Suggested by Author	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Not Applicable	50	

Figure 2A. Technical Report Standard Title Page. This page provides the data elements required by DoD Form DD-1473, HEW Form OE-6000 (ERIC), and similar forms.

INT: 2090-72

United States Department of the Interior

GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

February 2, 1973

Memorandum for the Record (EC-14-ERTS)

By: Cartography Coordinator, EROS Program

Subject: Thin cloud penetration capability of ERTS MSS band 7

It is well known that light at longer waves lengths has greater atmospheric penetration capability and that the near IR is a "haze cutter". Attached are samples of ERTS imagery which shows the degree to which the 0.8 to 1.1 μm wave lengths of MSS-7 penetrate thin clouds and contrails as compared to the visible spectrum as recorded on MSS-5. This is highly significant for the following reasons:

- It may explain why band 7 (or 6) often gives much clearer pictures in the eastern U.S. then band 5 which is the generally preferred single band in the west.
- It indicates that the use of this wave length might have a profound effect on aerial photography. At present IR aerial film cuts off at about 0.9 μm. However it is reported* that aerial film sensitivity can be carried much further into the IR and still retain acceptable resolution by using other than silver halide emulsions. This in turn indicates that acceptable photography for certain purposes might be obtained under atmospheric conditions that are now unacceptable. However, it should be noted that the IR response is different from that of the visible spectrum and many features normally seen in the visible will not be recorded in the IR.

*Verbally by George Zissis of the University of Michigan

Weather conditions at Harrisburg during the ERTS overflights are discussed in the attached memo by Mr. A.N. Brew

Alden P. Colvocoresses

Alden P. Colvocoresses

Attachments
1. Memo of Jan. 4 by Mr. Brew
2. Print of MSS band 5
3. Print of MSS band 7

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

January 4, 1973

Memorandum

To: EROS Cartography Coordinator

From: Chief, Branch of Aerial Photography

Subject: TOPOGRAPHIC SURVEYS - ERTS-1 imagery in vicinity of Harrisburg, Pennsylvania

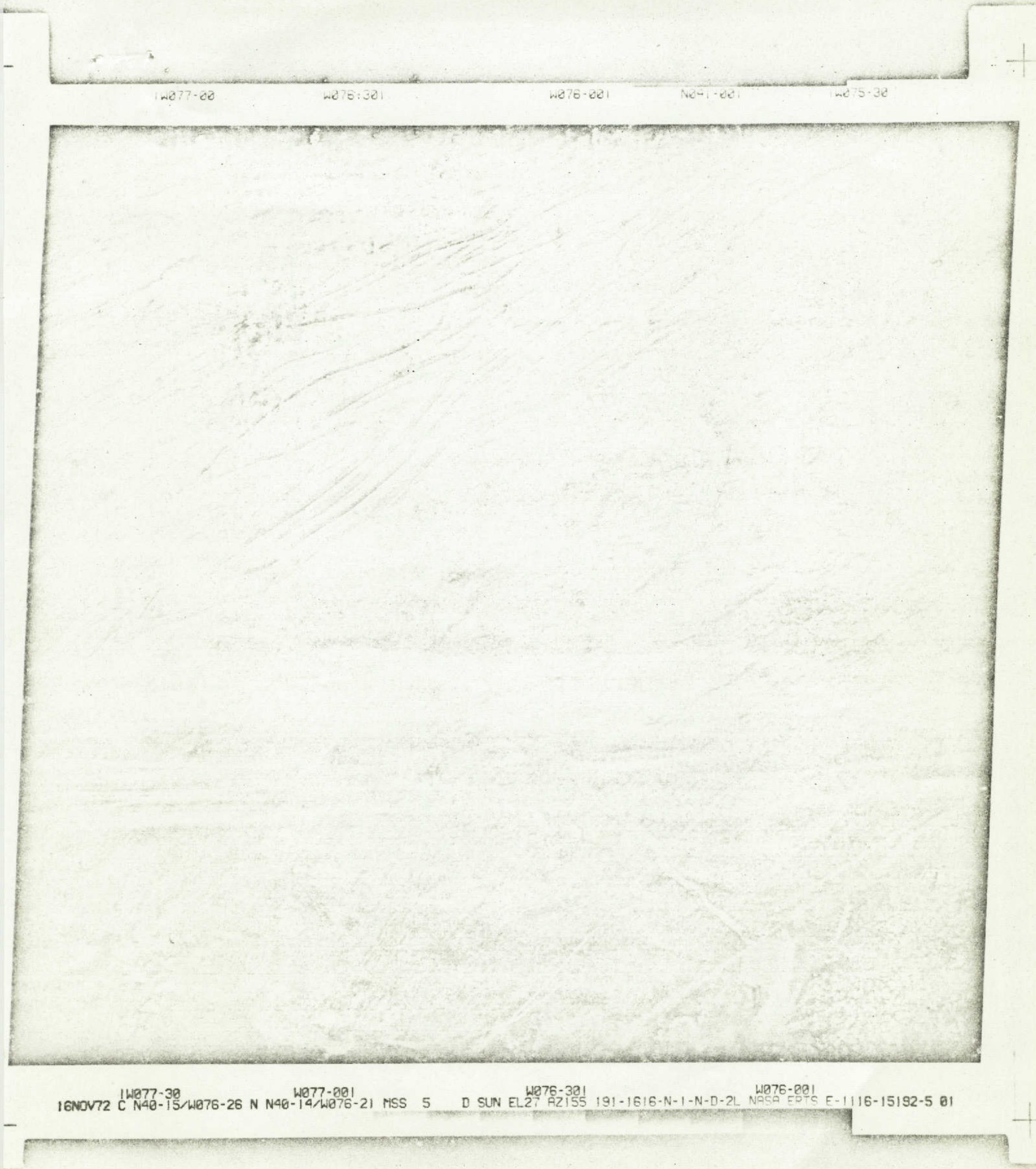
This will confirm our discussions about the several simultaneous frames of ERTS-1 imagery taken over the Harrisburg, Pennsylvania area. This exposure was taken at 10:19 a.m. eastern standard time on November 16, 1972.

Mr. Standifer has checked the weather conditions at Harrisburg at that particular time and finds that at 9:50 a.m. weather conditions were reported as being more than 15 miles visibility with thin broken clouds at 25,000 feet. An hour later, at 10:50 a.m., there was still more than 15 miles visibility with thin overcast at 25,000 feet. The station also reported no haze or smoke conditions at that time.

During this time we had in existence commercial contracts for both high and low altitude photography covering approximately 150 7½-minute quadrangles scattered throughout Pennsylvania. We gave the contractors notice to proceed beginning November 15. It is interesting to note that the high altitude crews have not yet been able to obtain any acceptable photographic coverage in the visible spectrum. They consistently have reported that on an otherwise clear day, they have been flying at 40,000 feet over a high thin overcast and were unable to photograph the project.

A. N. Brew

A. N. Brew



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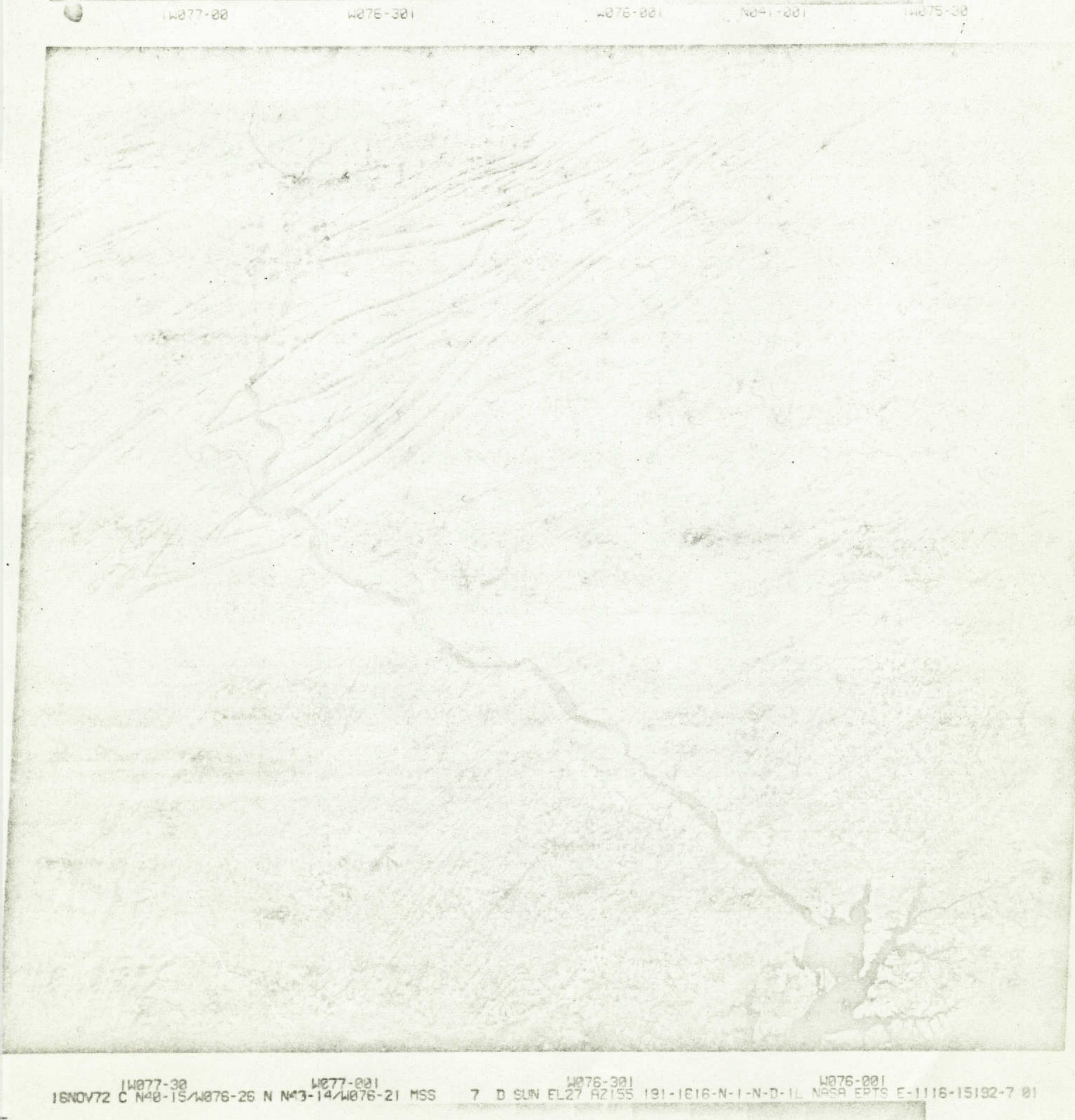

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United States Department of the Interior

GEOLOGICAL SURVEY

February 21, 1973

Memorandum for the Record (EC-15-ERTS)

By: Cartography Coordinator, EROS Program

Subject: Advantages of ERTS (TV) system over film return systems

The advantages of the film-return mode are well known and documented and it is only with the flying of ERTS-1 that certain advantages of the electronic transmission or TV mode became apparent. The more obvious of these advantages when compared to both aircraft and satellite film systems are as follows:

- Long life and coverage. Even after 6 months flying there are still sizeable areas of the U.S. not adequately covered by ERTS for cartographic purposes. It looks like a full year will be required to complete this coverage even though the cameras are turned on for every pass over the U.S. It is doubted that a single film-return satellite could be efficiently flown for such a lengthy period or even approach producing complete U.S. coverage. With luck ERTS-1 may survive for 2 or more years and thus achieve repetitive as well as complete coverage utilizing only one launch, spacecraft and instrument package.

- Near real time. The advantage of electronic transmission in near real time is obvious - even though the capability to realize this advantage has not been fully developed. Nevertheless a cartographic product has been developed in two weeks time after scene acquisition by ERTS.

- Radiometric fidelity. The ERTS signals, particularly those of the MSS are in effect those of a radiometer. As such they record with a range and precision well beyond the direct recording capability of any suitable film system.

- Extension into the IR wavelengths. Available aerial films cut off between 0.8 and 0.9 μm wavelength which is about the same as band 6 of MSS. MSS band 7 at 0.8 to 1.1 μm has opened a new window to remote sensing that is currently denied to our operational film systems. This band is enormously powerful and has demonstrated the following unique capabilities:

1. The effective penetration of thin clouds and contrails (under certain conditions) well beyond the current capability of film systems.

2. The definition of the water/land interface with a precision well beyond the current capability of comparable film systems - thus enabling the detection and identification of water bodies as small as 200 m diameter and the determination of water stage to a fraction of a meter through boundary correlation in flat lying areas. This is particularly significant when one considers that the instantaneous field of view of the MSS (spot size) is 79 meters. As an example of this capability differences in tide stage are obvious in sequential images of the mouth of the Colorado River.

3. The definition of vegetation patterns in a manner superior to film system. This is largely due to the differential sensitivity of band 7 to vegetation types.

4. The definition of natural features in a superior manner. Geologists (and others) are selecting MSS 7 as the best single band for depicting the earth's physiographic structure.

5. In some cases cultural features are best defined on band 7. For example the pattern of major streets in Los Angeles as so far recorded by ERTS.

It has been reported (EC-14) that aerial film systems are being developed abroad that cover the MSS-7 waveband. If and when such a development becomes operational the current advantage of the MSS-7 waveband would, of course, be reduced.

Alden P. Colvocoresses

Alden P. Colvocoresses

United States Department of the Interior

GEOLOGICAL SURVEY

April 25, 1973

Memorandum for the Record (EC-16-ERTS)

By: Cartography Coordinator, EROS Program

Subject: Scene Corrected (Precision Processed) ERTS Images

GENERAL

During the past few weeks NASA (Goddard) has initiated an extensive program of precision processing of ERTS imagery. Quality of these images has, in many cases, been surprisingly good and, as has been previously indicated, such images are in fact cartographic products which (as so far tested) meet National Map Accuracy Standards at the 1:1,000,000 scale and in some cases at 1:500,000 scale. Copies of these images in reproducible form are being sent to the EROS Data Center at Sioux Falls, S.D., but the extent of such coverage is not currently known as NASA production is based on specific requests from investigators.

Listings of available precision processed coverage are produced by NASA periodically as a computer tab run. Their standard catalogs fail to provide this information since precision processing generally takes place after such catalogs are issued, however it is understood that NASA will produce catalogs which cover the precision processed (scene corrected) products.

This memorandum does not cover all problems and unique cases that develop in precision processing. It is believed that NASA may publish pertinent instructions perhaps as a supplement to their ERTS Data Users Handbook. In the meantime this memorandum may prove helpful to users of ERTS precision processed products.

NASA criteria for annotating scene corrected images are covered on pages 3-9 and 3-10 of the ERTS Data Users Handbook, copies of which are attached hereto. Note that three choices are available to the requestor of precision products: (1) no internal ticks, (2) UTM internal ticks, and (3) geographic internal ticks.

LOWER LATITUDE PROBLEM

In the lower latitudes an ERTS image usually falls in a single UTM zone and thus presents the most simple case in which the UTM is a series of continuous straight lines. The UTM ticks, which are indicated on the inner side of the black scene border, can in this case be directly connected without error. Geographic meridians have very slight curvature on the UTM projection, and since this maximum curvature across a scene is only about 6 minutes of arc it can be disregarded and the geographic indicators of longitude (indicated on the outer side of the black border) connected directly. Except near the equator, latitude lines do have appreciable curvature and marginal latitude ticks cannot be directly connected. If internal geographic ticks are required and do not appear on the available version, latitude values must be computed. This can be done by the use of UTM tables or a computer program which gives the desired geographics in UTM values. As indicated, UTM values of the geographics can be precisely plotted. When internal geographic ticks are shown they can be directly connected without appreciable error.

Even at the lower latitudes imposing a full UTM grid, based on the marginal ticks, is difficult when a UTM zone boundary is involved. The Lake Tahoe scene (copy attached) illustrates such a case and shows how the UTM grid for the two zones involved can be developed. For such precision processed images which contain a zone boundary the UTM marginal ticks cannot be directly connected across the scene without serious error. If the scene carries internal UTM ticks across the scene (one of the options offered by NASA) the grid can be generated but will change direction at the UTM zone boundary which occurs at 6° intervals of longitude. If internal UTM ticks are not present the grid can still be constructed but requires a grid overlay or simple drafting instruments to properly construct.

HIGHER LATITUDE PROBLEMS

At high latitudes such as Alaska the problem becomes quite complex as the UTM zones are relatively narrow and two or even three zones may occur on the same image. In such areas the UTM zone boundaries must be plotted as well as such UTM Eastings (N-S lines) as can be identified along the top and bottom of the image. Dividers, a precise scale or a transparent grid template must then be used to establish the Northings (E-W lines) and these will again change direction at the zone boundary(s). It should be noted that values of ticks for the UTM Eastings appear only on the bottom of an image and that the values of the ticks for the UTM Northings appear only on the East side. Due to the increased angularity of the image with respect to North at the higher latitudes the number of corresponding marginal ticks on opposite sides of the image become greatly reduced. With respect to geographic determination at the higher latitudes, similar problems exists in that the number of geographic marginal ticks are greatly reduced and the curvature of the parallels increases with latitude. A print of a precision processed image of the Brooks Range in Alaska (with geographic internal ticks) will be furnished to those who request it of this office.

REQUESTS FOR PRECISION PROCESSED IMAGES

Users who request precision processed images from the EROS Data Center will have to accept whichever of the three forms that the Data Center has received and in many cases the precision processed image doesn't even exist. EROS investigators who do request precision processed images from NASA are advised to ask for the version that calls for internal UTM ticks to help alleviate the problems indicated.

Alden P Colvocoresses

Alden P. Colvocoresses

Enclosures

3.1.2.2 Image Format and Annotation

A sample of the SCCI image is shown in Figure 3-12. The alphanumeric and gray scale blocks at the left of the image area are copied directly from the SYCI image. The tick marks and alphanumeric annotation blocks in the lower left and lower right corners are unique to SCCI data and are explained in Table 3-2.

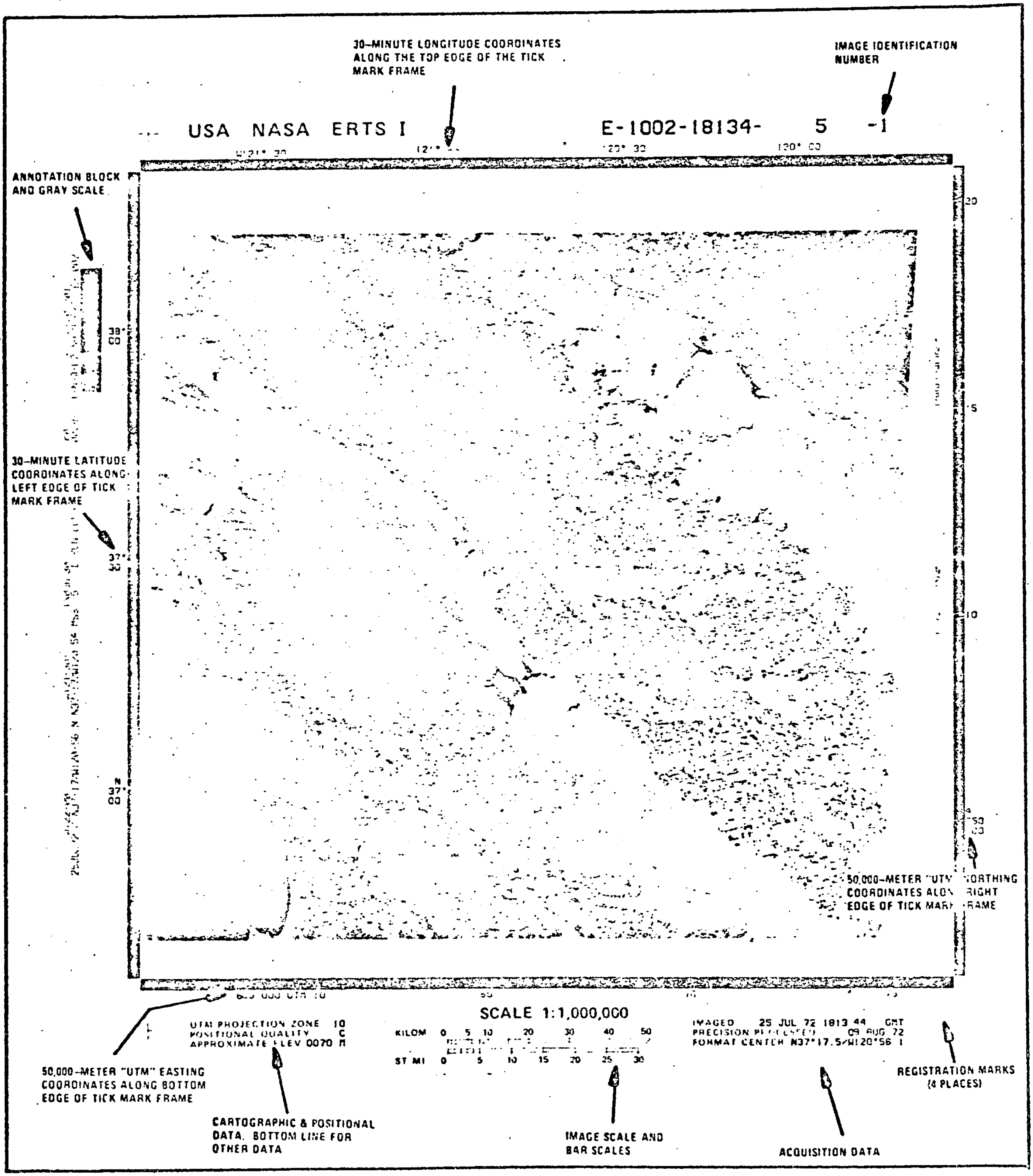


Figure 3-12. Scene Corrected Image Format (Not to Scale)

Table 3-2. Format and Annotation

A. TICK MARK ANNOTATION

The tick marks are individually printed in an unexposed band, 3 millimeters wide, framing the outer four edges of the image writing area and are slanted in the direction of the coordinate they designate.

The origin and length of the tick marks in the tick mark frame depend on the designated coordinate:

1. Latitude-longitude tick marks extend inward from the outside edges of the bands; even-degree ticks extend 2.3 mm inward, 30-minute ticks extend 1.0 mm inward. Degrees-minutes labeling is along the left and top margins.

2. Polar Stereographic Projection (PTP) tick marks are identical to the above. However, because latitude lines are curved, internal tick marks are always utilized (see below).

   Universal Transverse Mercator (UTM) tick marks extend outward from the inside edges of the bands; integral 100,000 meter ticks extend 2.3 mm outward; 50,000 meter ticks extend 1.0 mm outward. Labeling is along the right (Northing) and bottom (Easting) margins.

Each tick mark will be approximately 0.1 mm thick and oriented (inclined) to within ± one degree of the corresponding (N-S or E-W) direction.

B. INTERNAL TICK MARK CROSSES

When requested, small (2 mm) crosses designating the intersection of the map tick marks bordering the image writing area are printed upon the image. These tick mark lines are typically 0.5 mm wide. The crosses locate either geographic or UTM coordinates as follows:

In geographic coordinates, the crosses define the intersection of each 30 arc minute latitude with each

(a) 30 minute longitude for format-center latitudes between 0 and 60 degrees;
(b) one-degree longitude, for format-center latitudes between 60 to 75 degrees;
(c) even numbered degree longitude, (e.g., 0, 2, 4, . . . 356, 358 degrees), for format-center latitudes above 75 degrees.

In UTM coordinates, the internal crosses are located at

(d) the intersection of each 50,000 meter Northing and Easting coordinate.

The crosses are printed with a video intensity sufficient to produce a contrast of about 0.5 density units above the local image density.

C. CARTOGRAPHIC AND POSITIONAL DATA (lower left data block)

The first line indicates UTM zone number in which the image is projected. (Some images will include two UTM zones, but the projection will be in only one zone.) The letters "PS" will appear in this block if the image is a Polar Stereographic Projection

The second line indicates the positional quality as determined by computation of the Ground Control Point (GCP) residual errors. Letters A through D are used as follows:

Letter	Residual Error	
A	Very Good	(Few residuals)
B	Good	
C	Fair	
D	Poor	(Many residuals)

The third line is the approximate elevation in meters. It is a four digit number representing the elevation of the Ground Control Point (GCP) closest to the image center.

The fourth row of characters is reserved for special data. A "P" indicates Scene Correcting Subsystem Processing was done with predicted ephemeris; a blank (the normal case) indicates best fit ephemeris was used.

D. ACQUISITION DATA (lower right data block)

The first line is the date and time of image acquisition in Greenwich Mean Time (GMT).

The second line denotes the date at which the Precision image was printed.

The third line denotes the format center to the nearest tenth-minute in geographic coordinates.

3.1.2.3 Performance Characteristics

A complete discussion of the Scene Corrected product parameters is contained in Appendix F.

3.1.2.4 Delivered Form

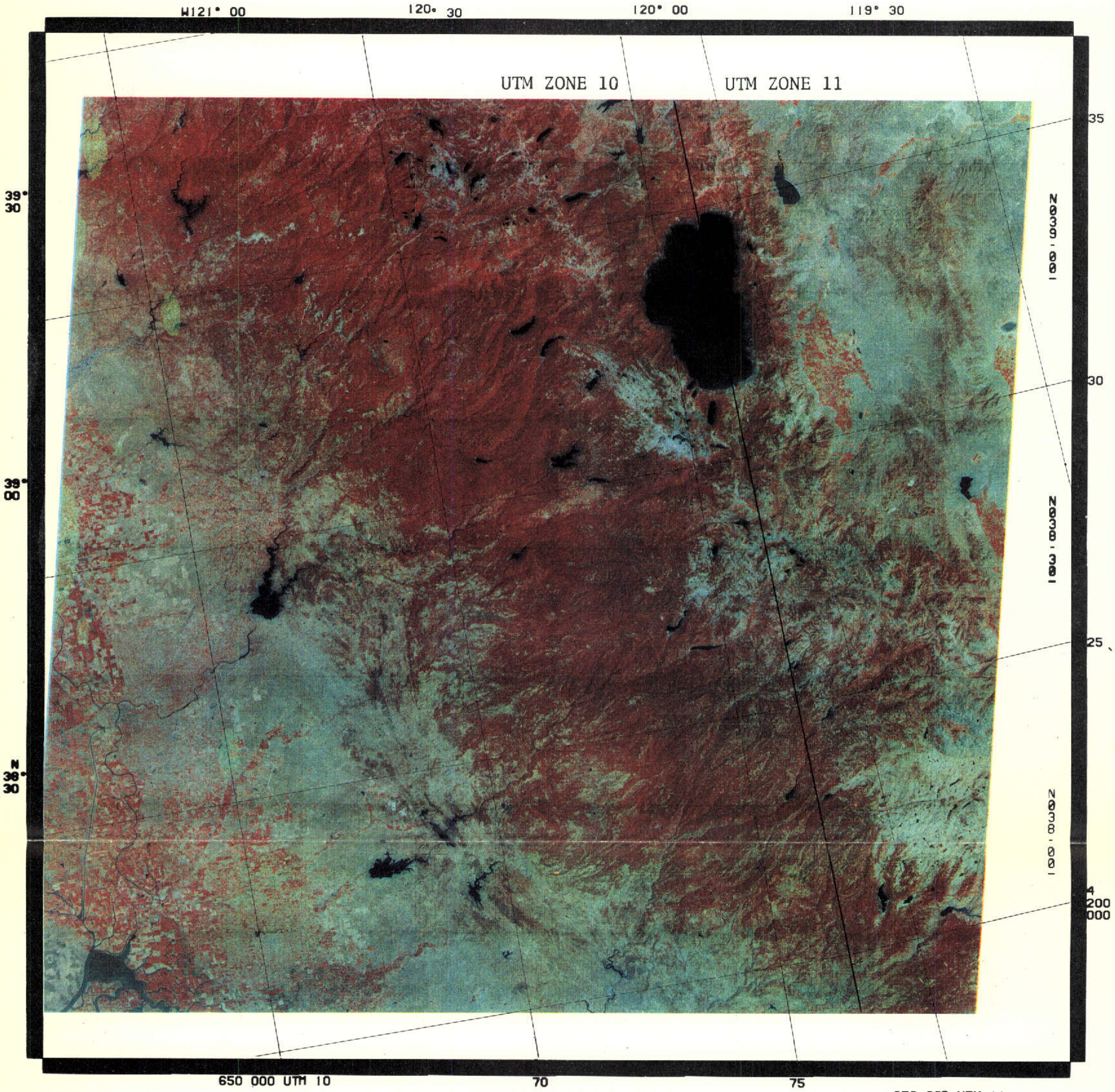
All SCCI photographic products are delivered as individually cut images.

3.2 COMPUTER COMPATIBLE TAPES

Digital data is available upon request in the form of Computer Compatible Tapes (CCT). These tapes are standard half-inch wide magnetic tapes and may be requested in either a

LAKE TAHOE AREA
CALIFORNIA — NEVADA

USA NASA ERTS I E-1002-18131- -1



SCALE 1:1,000,000

UTM PROJECTION ZONE 10
POSITIONAL QUALITY
APPROXIMATE ELEV 1010 M

KILOM 0 5 10 20 30 40 50
ST MI 0 5 10 15 20 25 30

IMAGED 25 JUL 72 1813:19 GMT
PRECISION PROCESSED 09 AUG 72
FORMAT CENTER N38°43.2/W120°27.6

EXPERIMENTAL ORTHOPHOTOIMAGE

THIS PRODUCT COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS

This orthophotoimage was produced within 15 days of exposure on semiautomatic equipment at the NASA data processing facility. It is a cartographic product from the Earth Resources Technology Satellite. The satellite is continuously orbiting the earth and recording such scenes at an altitude of 915 km. To provide such images of the earth, sensors of varying wavelengths aboard the satellite provide multiple images of each scene. Three of these initial images at 1:3,360,000 scale have been precisely restituted to ground control points and enlarged to a scale of 1:1,000,000. The three images originally exposed by different spectral bands have been cartographically merged by the USGS and lithographed as a false-color composite. Known geometric and radiometric errors in the initial images were removed and the cartographic quality improved. In the process the ground resolution is reduced. The square shading blocks are a result of the present system of precision processing.

EROS EARTH RESOURCES OBSERVATION SYSTEMS PROGRAM
In cooperation with NASA and other agencies

FOLDOUT FRAME 1

FOLDOUT FRAME 2

United States Department of the Interior

GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

June 11, 1973
(Corrected as of July 16, 1973)

Memorandum for the Record (EC-17-ERTS)

By: Cartography Coordinator, EROS Program

Subject: Status of Positional Referencing of ERTS Imagery

GENERAL

The recent ERTS symposium of March 1973 clearly indicated the need for automation in the field of remote sensing. Such automation involves two basic problems--first, identification of the imaged object and, second, position referencing in some absolute system. This memorandum deals with the latter problem of position referencing of ERTS and complements the information covered in Appendix F of NASA's ERTS Data User Handbook. Although systems such as space rectangular coordinates (X,Y,Z) might be employed, geodetic position as defined by an accepted figure (ellipsoid) of the earth is the absolute referencing system considered most acceptable at this time. Geodetic positions may be expressed in spherical coordinates in the form of latitude and longitude or in plane coordinates such as the Universal Transverse Mercator (UTM) grid.

ACCURACY OF THE ERTS IMAGE

In the following text, all accuracy figures indicate the root-mean-square (rms) value in terms of meters on the ground.

System-corrected (bulk) images as produced by NASA include geodetic position indicators in the margin. The accuracy of these indicators varies considerably, but it appears to be about 2 km. This applies to the latitude/longitude indicators along the margin as well as the indicators of the image center and nadir. This 2-km figure indicates the current potential of ERTS as a mapping system independent of ground control.

Scene-corrected (precision-processed) images have spatial reference of much higher accuracy than bulk and are in the 100- to 200-m range. The accuracy of the precision-processed image is controlled by the accuracy and density of identifiable ground control. Thus in areas where suitable control is limited (such as Alaska), precision-processed images will not have as high an accuracy as those of the conterminous U.S. NASA's precision-processed images have been rescanned and as a result lack the definition (resolution) of the bulk images, and point identification becomes a limiting factor in their use. The Canadian (and planned Brazilian) system of precision processing involves spatial modulation of the original digital tapes rather than rescanning, and thus image quality is preserved. NASA is experimenting with this same concept, and once successfully implemented such precision-processed images might well have positional accuracy of less than 100 m since point identification should be more precise.

A bulk MSS image contains certain systematic errors even after the corrections are made to approximate it to a perspective but continuous image of the curved earth surface. Therefore, fitting the MSS image to a defined projection such as the UTM results in positional errors in the order of 200 to 450 m. An alternative is to fit the (UTM) grid to the image, and this procedure has been initiated by the U.S. Geological Survey with respect to both images and mosaics of images in conventional map format. This procedure is based on ground control which must be transferred (preferably through a higher resolution image such as a photograph) to the ERTS image. A computer program (developed by Ohio State University under contract to the USGS) then develops the grid and graticule. The grid ends up as a series of straight lines with no more than one or two breaks in direction across the map. The resulting grid when used in conjunction with a manual measuring device such as a coordinate reader exhibits the characteristics of a true rectangular grid. The positional geodetic accuracy of points referenced to this fitted grid is in the 50- to 100-m range. It is believed that the lower figure can be consistently attained on a single image as methods of control identification and transfer are improved. The accuracy across a mosaic of two or more images will probably remain near the 100-m value even where control of a higher order is available. Where precise X-Y measuring devices such as a coordinatograph are used for digitizing data from such products, it must be recognized that the projection involved is not that of the grid and that coordinates must be referenced to the local grid lines rather than to any overall X-Y system.

LOCAL POSITIONING PROBLEM

By concentrating on a relatively small section of an ERTS image (1/16 or a square representing 46 by 46 km on the ground) in which at least two control points can be identified, the problem can be reduced to the point where geodetic positions can be considered for individual pixels, or even a designated point within a pixel.

In order to assign a geodetic position to a specific pixel or point therein the following sources of errors must be considered:

Accuracy of control (1)
Point transfer (2)
Pixel size (3)
Local pixel displacement (4)

1. Accuracy of Control

Control points will generally have no better geodetic accuracy than the best available line map of the area of concern. USGS 1:24,000-scale line maps have a positional accuracy for well-defined features (black plate) of about 8 m, and the 1:62,500-scale maps of about 20 m. For 1:250,000-scale maps (the only scale of complete U.S. coverage) the positional error for well-defined features is in the order of 100-150 m in the 48 States and even larger in Alaska. For other countries the accuracy of suitable control will vary according to the status of mapping.

For the more populated areas of the U.S., the figure of 8 m is considered appropriate.

2. Point transfer (marking and measuring).

The single most critical step in relating ERTS imagery to a geodetic system is in the identification and designation of known ground control points on the imagery. In the direct manual approach to this problem, it would appear that the scale of the image would be critical, but in practice little differences are noted as long as the human eye can see the image detail and the designation (marking) device is of sufficient precision. The optimum scale appears to be 1:500,000, although point designation has been successful at both 1:1,000,000 and 1:250,000 scales.

In practice, the direct transfer of a map-identified control point to an ERTS image results in an error of about 30 m, which is independent of the map accuracy. This 30-m transfer error can be significantly reduced by the use of an intermediate image of resolution several times better than that of ERTS. The expected imagery from the Skylab ETC (18" f.l. frame camera) experiment provides the type of intermediate image desired, but small-scale aerial photos can also be used. By transferring a well-defined control point from the map to the higher resolution image and then to the ERTS image, the transfer error in each case is in the order of 10 μm. At 1:1,000,000 scale, 10 μm equals 10 m, and since two such errors are involved (2 transfers) $10\sqrt{2} = 14$ m. If transfer is accomplished at scales larger than 1:1,000,000 this figure will be further reduced. Thus the 30-m error of direct control transfer to ERTS may be reduced to 14 m (or less) by use of suitable intermediate imagery, and this procedure is recommended whenever possible.

3. Pixel Size

The ERTS pixel or instantaneous field of view represents a nominal 79-m square even though it prints out at about 79 m by 56 m due to a pixel overlap in the cross-track direction. Based on random distribution for discrete points within the pixel, the rms distance from the pixel center is about 37 m.

However, for a point which has a known geometric relationship to other points, this error can be materially reduced. For example, the corner or intersection of a large field on an ERTS image may be located by using an array of pixels which define sizeable lengths of the field's lines. Since the resulting corner position is in effect a least-squares fit of the involved pixels, considerable improvement in the field-corner position will result. The extent of this improvement has not been fully determined emperically, but if individual pixels were relatively located to 37 m, the use of 16 such pixels would theoretically bring the corner location to within 10 m (9.25) since $M = \frac{m}{\sqrt{n}}$ when m = 37 and n = 16

The above indicates the reason for selecting control points such as road intersections or centroids of circular features, since the location of the control point can be defined by the array creating the geometric form or pattern. When correlating between ERTS and higher resolution imagery, the control point need not be part of a geometric pattern as long as an array of local features on both ERTS and the higher resolution image can be correlated and the control point can be defined on the higher resolution image. However, there is a practical limit to this approach since the geometry of the ERTS and higher resolution image are not identical.

4. Local pixel displacement

Table F.1-3 on page F-5 of the ERTS Data Users Handbook lists the internal errors in the MSS, some of which create local pixel displacement. Those believed applicable include Random Cross Scan Jitter (1.8 m), Scan to Scan Repeatability (3.6 m), Scan Start and Scan End Variation (5.6 m), and Detector Alignment (8 m). These four errors combine to a value of about 10 m (10.5 m). In addition to these a further error referred to as the sweep to sweep bias occurs between each group of 6 scan lines on all MSS bulk imagery processed by NASA prior to April 1973. This results in an offset which as measured to date is in the order of 55 m. The resulting error should vary from 0 to 28 meters with an rms of 19 m. The 10-m and 19-m errors combine to 21 m for the local pixel displacement.

During April 1973 NASA took steps to correct this sweep to sweep bias to the extent that it is all but eliminated at the mid-latitudes. Since one of its components is due to earth rotation some bias (error) still exists at the equator and at maximum latitude (81°). The rms of this error for all MSS imagery processed by NASA after April 1973 is estimated at 8 m. This 8 m and the previous indicated 10 m error combine to 13 m and this is the error figure considered proper for current MSS imagery.

The above listed errors are basically independent and therefore subject to normal error propogation. Thus $E = \sqrt{e_1^2 + e_2^2 + e_3^2 + e_4^2}$, and by introducing the four desired values we get $E = \sqrt{8^2 + 14^2 + 10^2 + 13^2} = 23$, which can be rounded to 25 m. For imagery processed prior to April 1973 the figure of 30 m is suggested.

Thus 20 m is the estimated rms by which a discrete point can be defined and geodetically referenced on a portion (1/16) of a current MSS image in which at least 2 control points can be identified.

SUMMARY OF MSS SPATIAL PROBLEM

Image mode and form of geodetic indicators	Expected error in geodetic position under optimum conditions (rms)
Independent of ground control	
MSS bulk--marginal indicators of lat/long	2,000 m
With ground control	
MSS precision--marginal or internal indicators of lat/long or UTM	100 - 200 m
MSS bulk--best fit to (UTM) projection	200 - 450 m
MSS bulk--grid fitted to image	50 - 100 m
Localized (1/16 of an MSS bulk image) fit of a specific point in areas where at least 2 control points are available and imagery was processed after April 1973	25 m
(For MSS imagery processed prior to April 1973)	30 m

CONCLUSIONS IN CARTOGRAPHIC TERMS

The above summary leads to the following conclusions relative to ERTS MSS imagery:

1. It is not suitable for independent mapping (without ground control) to accepted (National) standards at scales larger than 1:5,000,000.

2. Precision imagery as now processed by NASA is positionally commensurate with 1:500,000-scale mapping, but image quality (perceptional characteristics) probably limits its useful scale to 1:1,000,000.

3. Bulk imagery cannot be fitted to a conventional map projection with any assurance of positional accuracy (NMAS) at scales of 1:1,000,000 or larger.

4. By controlling and fitting a plane coordinate (UTM) grid to a bulk image, positional accuracy meets or approaches that of a 1:250,000-scale map of standard (NMAS) accuracy.

5. In areas where local control is available, clearly defined features on ERTS imagery can be transferred for revising maps as large as 1:100,000 or 1:125,000.

6. The ultimate precision for geodetically defining a specific point on an ERTS image under optimum conditions (including good ground control) is in the order of 25 m (rms).

Alden P Colvocoresses

Alden P. Colvocoresses

United States Department of the Interior

GEOLOGICAL SURVEY
1340 Old Chain Bridge Road
McLean, Virginia 22101

August 1, 1973

Memorandum for the Record (EC-18-ERTS)

By: Cartography Coordinator, EROS Program

Subject: Map Projection of the Bulk (System Corrected) ERTS MSS Image

Defining the Projection

Recently the USGS successfully fitted the Universal Transverse Mercator (UTM) grid to selected ERTS Multispectral Scanner (MSS) bulk images and mosaics of images at 1:250,000 scale. Maps so produced are in fact cast on the projection of the MSS image, which to date has not been fully defined as a specific map projection. The conventional mapping approach is to use a projection of the earth's figure, such as the UTM, and either transform the image to this projection (precision processing) or force the bulk image to the best analog fit on the projection. Because ERTS provides near orthographic imagery, the grid of a conventional projection, such as the UTM, can with only minor distortions be fitted to the MSS bulk imagery, except in isolated areas of extreme relief. The grid distortions are real and can be measured with precision instruments but they are less than 1 part in 1,000--which is the criterion, more or less, for maps of scaling accuracy. Moreover the fit appears consistent, which indicates that the bulk image of ERTS is itself a map projection of the earth's surface.

NASA/ERTS Users Data Handbook (1)* describes the orbit, MSS scanner, and geometric corrections made to the imagery; and Konecny (2), Kratky (3), Forrest (4), and the undersigned (5) have described the basic geometric and mathematical relationships of the ERTS image to the earth sphere and the UTM projection. Konecny further indicated that ERTS bulk imagery would be printed out in the UTM projection, whereas Kratky defined the corrected MSS image (bulk) as representing the equidistant cylindrical or Cassini projection. However an analysis of the geo-

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*According to this reference, one of the corrections is a scale change in the along-track direction to approximate the perspective view of the RBV frame image. In practice this so-called correction--which is actually undesirable except for correlation to the RBV--has not been generally applied by NASA.

metric corrections made by NASA (1) indicates that neither the UTM nor the Cassini is the actual case. NASA has in fact retained the geometric conditions of perspective, which transform the individual panoramic sweep of the scanner (six lines) into a narrow horizontal strip on the plane normal to the vertical and at an equivalent focal distance* above the optical center of the primary mirror of the scanner. Attached are diagrams and notes which cover the basic geometry and mathematics of the MSS scanner. The resulting thin strips when properly composited and normalized to a scale of 1.00000 form a cylindrical surface around the earth normal to the orbital plane and tangent to the figure of the earth.

This cylinder or ring is fixed in space with respect to the polar axis, and forms a simple cylindrical surface of projection. The perspective centers of the strips that comprise this projection form a circle which is the loci of points occupied by the optical center of the scanner. Since a cylinder can be converted to a plane without distortion, we have the essential elements of a map projection. At any given instant of time the MSS scanner is pointed to a discrete (79 m) element of the earth, and this element is in turn recorded as a discrete picture element on the described projection. Map projections are normally defined and fixed with respect to the surface of the earth, but in this case the projection is independent, and an equation involving four motions as functions of time must be introduced to relate the projected image to the earth's surface. The four motions, all of which have a defined time relationship, are involved in the image formation as follows:

- The mirror sweep in the nominally cross-track direction
- The satellite orbit in the along-track direction
- The rotation of the earth, which provides the continuous shifting of the earth scene with respect to the orbit (and projection).
- The precession of the orbit.

These four motions result in the (potentially) complete mapping of the earth from 82° N to 82° S every 18 days on the same defined projection and in a sun synchronous mode.

For want of a better term, this projection is dubbed <u>Space Cylindrical Strip Perspective</u>: <u>Space</u> because it is defined and fixed in space, <u>Cylindrical</u> because of its shape, and <u>Strip Perspective</u> because it retains the geometric properties of perspective in the strip resulting from the scanner sweep. Such a projection could undoubtedly be applied

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*This distance is irrelevant but is introduced to equate the MSS to an optical imager. For convenience a scale of 1.00000 is suggested. However the diameter and F number of the scanning mirror provide a focal length of about 0.76 m.

to other circular orbit systems which utilize a point or slit type imager (scanner, panoramic or strip camera). Insofar as is known, NASA or NOAA have not used this approach for meteorological satellite imagery, which they normally transform to one of the conventional projections, such as Miller cylindrical, azimuthal equidistant, or point perspective (for ATS).

Characteristics of the Present MSS Projection

The basic characteristics of the MSS projection are summarized as follows (see attached notes):

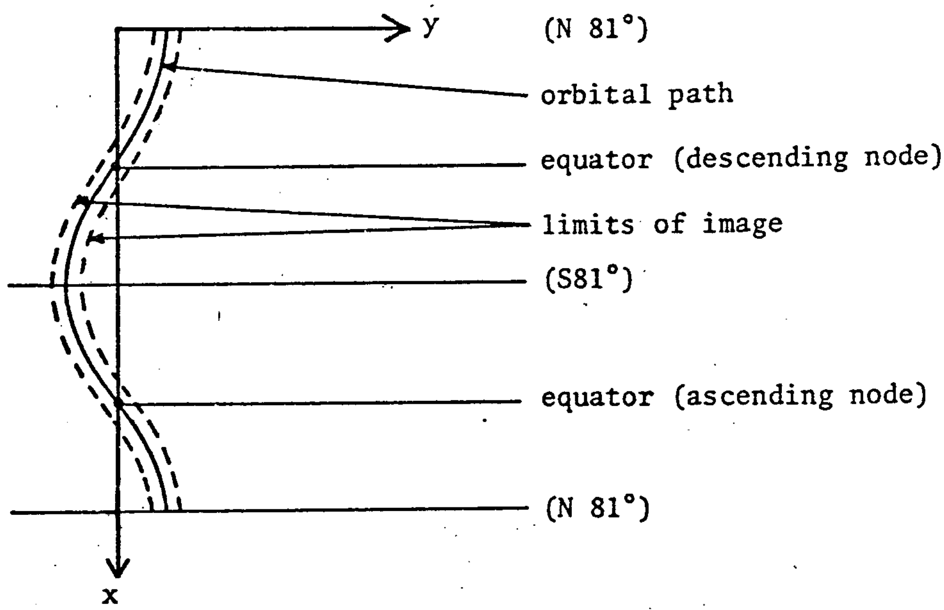
- Scale at nadir can be any desired scale, but we will normalize it with a scale factor of 1.00000.
- Cross track scale factor at image edge (end of scan lines) is 0.99916.
- Along track scale factor at image edge is 1.00011.

This results in a nonconformal projection in which an affine condition exists except along the nadir path. Thus the scale is different in different directions, and angular relationships will not truly hold as they do on a conformal projection. Nevertheless it is a true map projection insofar as NASA can correct for the various anomolies involved (1) and a system of plane cartesian coordinates can be applied to the projection. These coordinates become related to the earth's surface only when the four described motions are introduced as a function of time. This relates a specific element of the earth's surface to a specific element of the projection. Developing this transformation presents an interesting mathematical exercise which is by no means trivial if such refinements as the ellipticity of the earth's figures are considered. However if the projection is to be used as such, the rigorous transformations must be developed. Konecny (2) and Kratky (3) have indicated the general form of the mathematical relationships involved. Although the cylinder is fixed in space at a prescribed angle of about 9° to the polar axis, the earth or the cylinder must move back and forth along the cylindrical axis. This relative linear motion provides for the continuous imaging of the rotating earth on the cylinder without discontinuities.

If we start with an origin at the point of maximum inclination (N 81°) the (x) along-track coordinate value will increase indefinitely.* The mapping equations of the earth surface must account for the various orbits, which after 18 days (251 orbits) would mathematically repeat themselves providing that the prescribed corrections are all properly made. The y or cross track coordinate value must accommodate the linear motion of the earth in the cylinder of projection. This motion results

*By treating the projection plane as a cylinder (which is mathematically acceptable) the x values repeat themselves each orbit.

in the orbital path (and the image strip) being record on the projection as a sinusoidal line (strip) which oscillates back and forth in the y direction as follows:



Map projection of MSS

Although the imagery is recorded on a single projection, there are always discontinuities between imagery of adjacent orbital passes when it is laid on the same plane (map). This is because the scale must change in the cross-track direction, and the orbital passes are convergent. Thus the cross-track distance from the nadir (center line) is constantly changing. The discontinuities are very small when the imagery is correctly processed, but they are real and are equivalent to the gores one sees in the zone boundaries of such transverse Mercator projections as the UTM.

Practical Application

The MSS projection (Space Cylindrical Strip Perspective) is in fact being used today for experimental mapping by the USGS and any others who map directly with MSS bulk imagery. In order to produce maps that are readily understandable, we are imposing a conventional plane coordinate grid to this heretofore unconventional projection. The grid selected is the UTM, and the resulting distortions of the UTM grid on this projection are so small (generally less than 1:1,000) that the average map user cannot detect the discrepancies. By relating image points to the local grid lines there is no measurable error due to the projection, and it is only when stable base manuscripts are measured on a precise measuring machine, such as a coordinatograph, that the discrepancies in scale and direction can be detected.

Recommended Changes

NASA's printing of the MSS bulk imagery is modulated by a computer (EBRIC).* Thus there is no great problem in introducing a mathematical change in the printing procedure. Rather than print out on the presently used semiperspective affine projection, it is recommended that the projection if possible be made conformal. A cylindrical surface is still involved, and the only defined conformal cylindrical projection is the Mercator which may be normal, transverse, or oblique to the earth's polar axis. This is the oblique case with the plane of the orbit that defines the cylinder at 9.092° to the polar axis. The equations relating the oblique Mercator to the figure of the earth have been developed in detail for the various ellipsoids as well as the sphere, (6) but all are based on the static case. Here, as with the present MSS projection, we must develop the transformations as a function of time. A suitable name for this recommended projection is Space Oblique Mercator. As defined herein, this projection is not truly conformal since the two axes on which the equal-scale condition of conformality are established vary up to 4° from orthogonality. Thus a truly circular feature on the figure of the earth will have a very slightly elliptical form to it on the projection, depending on its position on the orbit. This elliptical distortion of a circle is known as Tissot's indicatrix and graphically illustrates the mathematical condition of nonconformality. Since the geometric conditions which create this slight deviation from conformality can be expressed mathematically, the relationships between the figure of the earth and the projection are still rigorous. Insofar as the actual image is concerned, the deviation from conformality will not be measurable and for analog applications can be disregarded. Perhaps Gerhard Kremer (Mercator) would object to having his name applied to a projection which is not truly conformal, but since conformality is the primary consideration applied, it is believed that this projection should be associated with Mercator.

The projection cylinder can be defined as either tangent or secant to the (sea level) figure of the earth. U.S. sponsored projections such as the UTM and those of the State plane coordinate systems are secant, whereas most Europeans use tangent projections, the most common being the Gauss-Kruger which is transverse Mercator. The projection of the Space Oblique Mercator creates scale distortions of only slightly over 1:10,000 and it is recommended that the European practice of tangency be followed. On a tangent cylinder, the scale factor of the projection, except along the orbital track, is too large with respect to the figure of the earth. However the land masses of the earth (where the MSS is principally employed) have mean elevations of 340 m or more (the mean elevation of North America is reported as 720 m). A mean elevation of 340 m, which is found in Europe and Australia, would compensate for the projection scale factor so that insofar as projection distances are concerned, as compared to actual ground distances, there is no valid

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*Electron Beam Recorder Image Corrections.

argument for making the projection secant. Insofar as fitting the MSS projection to the UTM, it makes no real difference since the scale factor of the UTM varies from 0.9996 (at the central meridians of the zones) to 1.0010 at the zone edges along the equator. Thus it is recommended that the MSS projection scale factor be 1.0000 along the orbital path and 1.00011 along the image edge.

Although they are probably not feasible to implement on ERTS-1, certain other alternatives should be considered relative to the projection of the MSS for future ERTS-type satellites. For instance, the EBRIC could include an along-track scale change based on the UTM zones. This would modulate the scale factor from a maximum of 1.001 to 0.9996. Such modulation would be an irregular approximation and require updating from ephemeris data. Moreover, scale modulating the imagery would be a disadvantage to anyone not using the UTM or the Soviet Unified Reference System, which is generally compatible with the UTM. Such UTM simulated modulation would not be implemented in the polar regions where another modulation might be introduced to approximate the scale factors of the two polar stereographic projections as now defined for the precision processing of ERTS imagery in the polar regions. Actually the precise UTM (and polar stereographic) projections could be used, but this involves discontinuities (breaks in the imagery) at the zone boundaries, the application of complex mapping equations, and calibration against ground control to fully implement. Perhaps such a system can be developed for near-real-time application in the future, but for the present, it is believed that NASA should concentrate on the relatively simple space Oblique Mercator for bulk processing. Insofar as possible, NASA should experiment with the alternate proposed projections (and perhaps others) to assist in the formulation of definitive plans for the processing of imagery from an operational ERTS-type satellite.

Significance

Defining the projection of the MSS in mathematical terms is essential to all who would relate the ERTS pixel* to the figure of the earth. The form of this projection is immaterial to those who deal strictly in analytics (computations) as long as it is rigorously defined. For those who use the MSS image for mapping in anolog mode, the image projection should conform as close as possible to the mapping projection used for final display. ERTS imagery, except for that of polar regions, is customarily displayed on the UTM projection. The adoption of the Space Oblique Mercator by NASA would provide a continuous single projection which develops projection scale distortions of only about 1 part in 10,000 and which has geometric properties somewhat comparable to the UTM. Eventually, the automated casting of the image on the actual UTM projection is a distinct possibility.

From a practical standpoint, any attempts to fully automate an MSS mapping system will be limited by the precision of ephemeris and at-

*picture element

titude data, which to date results in errors in the order of 2 km (rms). However the user can normally find at least one control point against which he can calibrate an MSS image or even several contiguous MSS images of the same orbital pass. With such calibration data and the mapping equations developed in rigorous form, he can then compute and superimpose on his image the figure of the earth in the form of lat/long or plane (UTM) coordinates. There are today indications that with control of perhaps 100 to 200 km spacing a printed map can be prepared that meets National Map Accuracy Standards at 1:250,000 scale (80 m rms). On the present MSS projection the resulting maximum distortion of the UTM grid is in the order of 0.25 mm (0.01 in.) on a 1:250,000-scale map, but on the recommended Space Oblique Mercator projection this distortion would be considerably less. The MSS, as system-corrected by NASA, is creating a continuous image of the earth on one single projection. Moreover it is doing it with a precision which opens the door to semiautomated image mapping today and perhaps fully automated image mapping within a decade. In this context the word mapping refers to digital as well as analog relationships.

It is important to note a basic advantage of the scanner as compared to the frame imager (camera). A frame imager creates its own discrete projection with each exposure. At aircraft altitudes, the effect of earth curvature is minimal, but from space it is significant. If a map is to be made by analytical procedures, there is no problem; but if the image is to be used in analog form as a map base, the problem is real because the discontinuities between images become measurable. With a scanner such as MSS the image produced is more or less continuous and (insofar as corrections are made) always on the same projection. For the first time the entire earth (between N 82° and S 82°) is being mapped on a single map projection on which the projection scale distortion is always less than 1:1,000 and, if made conformal, about 1:10,000. It is true that the imagery from two adjacent orbital passes cannot be fitted together without some discontinuity, but the imagery itself has the same geometric characteristics which continue without disruption along the orbital path.

The net effect of this new concept of mapping cannot be forecast at this time. Its basic importance to the mapmaker is obvious, but it is probably of equal or greater importance to those who use the digital approach to store and analyze data relative to the earth's surface. In theory, if not in actual practice, the mathematical relationship between the ERTS pixel and its location of the earth can, through the projection, be rigorously defined.

Acknowledgement

This memo represents a combined effort on the part of the EROS Cartography Program. In addition to those cited the branches of Photogrammetry and Field Surveys, Office of Research and Technical Standards, Topographic Division, U.S. Geological Survey performed the computations and measurements which led to the definition of this projection. In essence it is NASA who created the projection when they defined ERTS

and then so successfully applied corrections to the raw MSS data.

Alden P Colvocoresses
Alden P. Colvocoresses

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4. Forrest, R.B., Mapping from Space Images, Bendix Technical Journal Summer/Autumn 1970.

5. Colvocoresses, A.P., ERTS-A Satellite Imagery, Photogrammetric Engineering, June 1970.

6. Thomas, Paul D., Conformal Projections in Geodesy and Cartography, Sp. Pub. No. 251 of Coast and Geodetic Survey, G.P.O. Washington, D.C. 1964.

Notes on ERTS MSS Projection of Bulk Imagery*
(see attached diagrams)

H = altitude of satellite = 900-950 km

R = mean radius of earth = 6,367 km

β = viewing angle of scanner with respect to nadir (max = 5.76°) The plane of the scanner motion is now defined as perpendicular to the plane of the orbit

γ = angle of earth curvature involved (max = 0.83°)

f = effective focal length of scanner. Based on mirror size and F number this is 730 mm, however, this dimension is immaterial with respect to the projection.

N = nadir point

P = point on earth imaged by MSS sensor

Present MSS projection (space cylindrical strip perspective)

C = line on which scanned image is recorded. Panoramic effect of scanner has been corrected to provide a true to scale image of a flat earth as depicted by tangent plane T. When scanner and satellite motions are introduced the line C generates a cylinder at height H + f above the spherical earth.

Assume scale factor at nadir = 1.00000 (tangent cylinder)

Perspective cross-track scale at P = M = $\underbrace{\frac{H}{H+D}}_{\text{(dist. effect)}}\underbrace{\cos\gamma}_{\text{(primary obliquity effect)}} = \frac{H\cos\gamma}{H+R(1-\cos\gamma)}$

At max scanning angle M = 0.99916

This cross-track scale varies from 1.00000 at nadir to 0.99916 at image edge.

In the along track direction the nadir point N and image point P at a fixed scanning angle (β) must describe lines on cylinder C (image) of equal length in order to provide the continuous image of the MSS. This condition requires that the along track scale at P must be larger than at N by an amount equal to the secant of γ. At maximum scan angle this along track scale equals the secant of 0.83° or 1.00011.

Projection is cylindrical and perspective in cross track direction only. One single projection (zone) maps the entire earth between the 82° parallels every 18 days.

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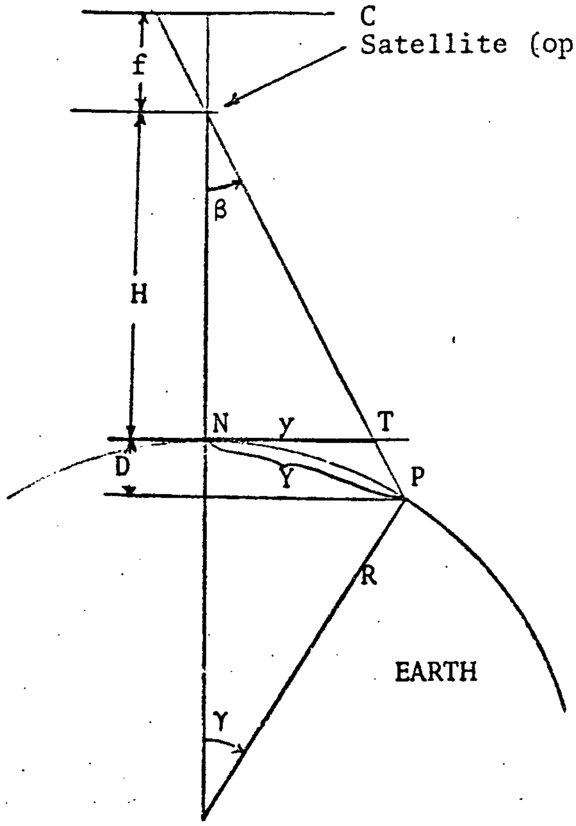
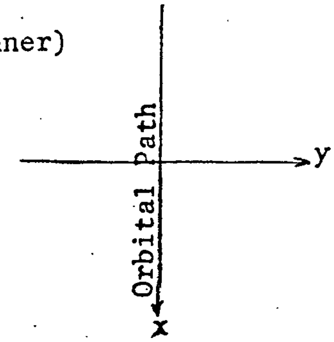
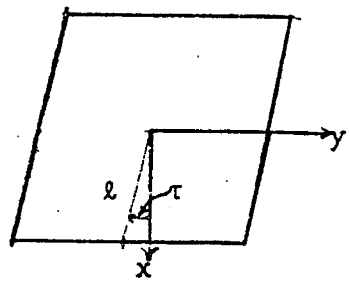
*All figures given are approximations. NASA is expected to make available exact figures which might be required for rigorous computations.

Geometry of ERTS, MSS (orbital plane is perpendicular to this plan).





Projection Plane (T)



Skewed image on projection plane
$x = \ell \cos\tau$

Let X = dist. along suborbital path on earth figure (stationary sphere)*
Y = dist. normal to suborbital path on earth figure $Y = \gamma R$*
x = dist. on projection plane (cylinder) in orbital plane
y = dist. on projection plane from orbital plane
ℓ = actual orbital path as imaged τ = skew angle (varies with latitude)

On present MSS projection:

$$x = X$$

$$y = R \sin\gamma \left(\frac{H}{H+R(1-\cos\gamma)}\right)$$

On recommended projection (Space Oblique Mercator)

$$x = X$$

$$y = R\int \sec\gamma \, d\gamma = R \log_e(\sec\gamma + \tan\gamma) = R \log_e \tan\left(\frac{\gamma}{2} + \frac{\pi}{4}\right)$$

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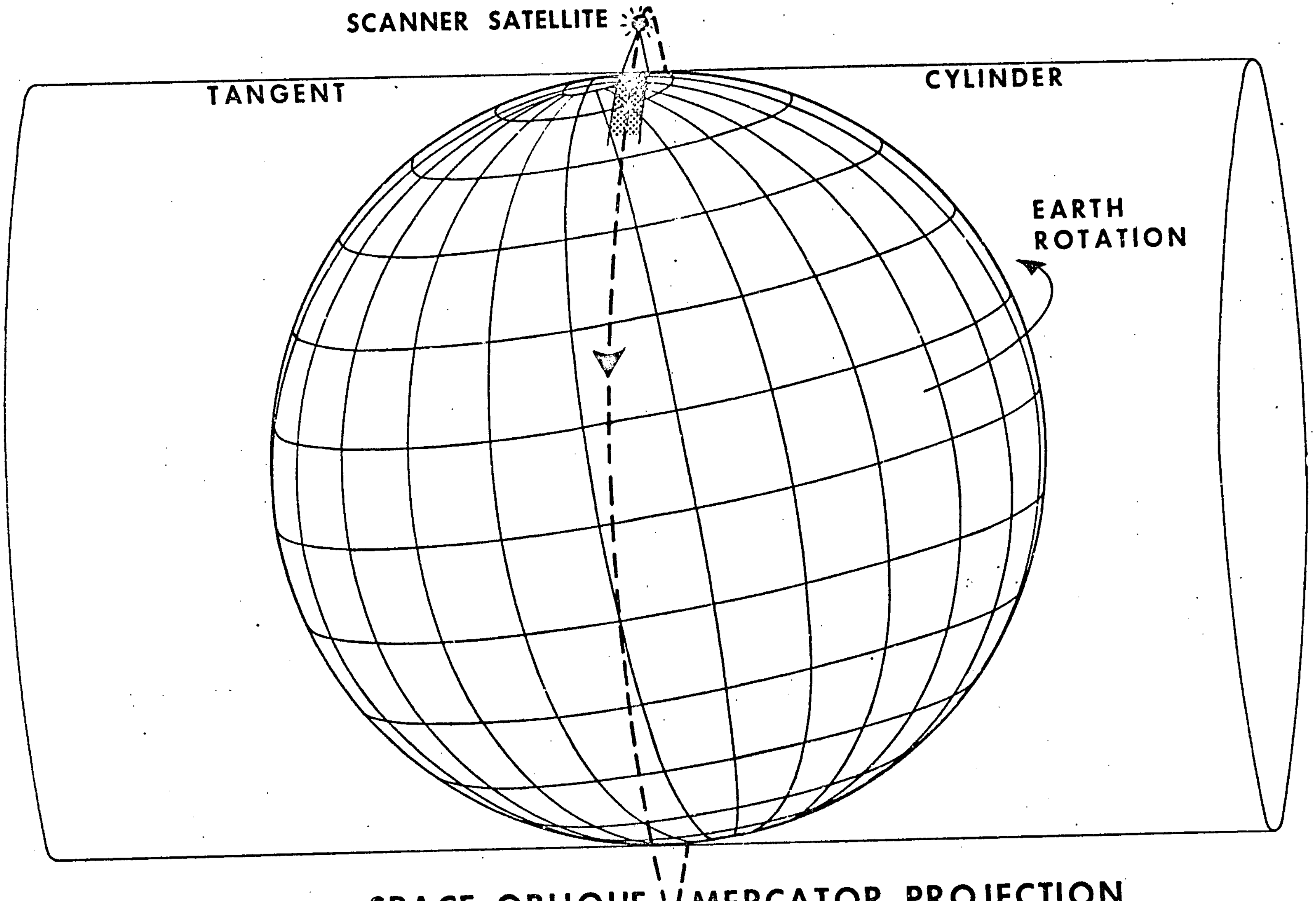
*If one disregards the small error introduced by earth rotation during the scan sweep (The maximum displacement in the x direction is only about 200 m for the 185 km scan length), the y direction on the actual image is that of the scan lines (as now configured). However the x direction of the projection will be skewed on the image by as much as 4° with respect to the image orbital path, again due to earth rotation.



SPACE OBLIQUE MERCATOR PROJECTION

Images the Earth from N 82° to S 82° every 18 days

MOTIONS INVOLVED

- Scanner sweep
- Satellite orbit
- Earth rotation
- Orbit precession

7/73

United States Department of the Interior

GEOLOGICAL SURVEY
WASHINGTON, D.C. ~~XXXXX~~ 20244

June 29, 1973

Memorandum for the Record (EC-19-ERTS)

From: Research Civil Engineer (RT-P)

Subject: Status of the ERTS image format as the basis for a map series

This memorandum on the above subject has been prepared at this intermediate point because numerous people are becoming interested in the subject and should be informed of our progress. Hopefully it will prevent a duplication of effort and allow a unification of direction and application.

Investigations were performed by the Topographic Division (RT-P) and others on the level of geographic repeatability of ERTS-1 images. Orbits and along-track image centers were found to have been maintained by NASA within approximately ± 15 km and ± 5 km respectively. It was also determined the orbit control could be maintained to ± 5 km if requested. This is within one-half the 10% overlap (9.25 km) along-track and one-half the 14% sidelap (12.95 km) at the equator. (Sidelap increases away from equator.) Therefore a plot of predicted ERTS-1 nominal scenes seemed practical and desirable as a possible basis for a series of ERTS image maps.

A FORTRAN computer program for generating worldwide predicted image centers was obtained from Tim Horn's GE group at Goddard Space Flight Center. Different formats of image plotting were then studied. The most obvious, locating the image center and drawing the full-size frame, was discarded because overlap between images would clutter the plot and reduce the free space, especially in the higher latitudes.

Other formats were investigated with the most promising being a "bisector" scene. The format outline is formed by lines drawn midway between the nominal scene centers (bisector lines) forming quadrilaterals that do not overlap their neighbors (see figure 1). An algorithm to compute the geodetic latitude and longitude for any scene center and the four corners of the bisector format has been written and is presently being programmed for the digital computer.

An algorithm that generates a unique identification number for each scene is also written. Each ID number is composed of 11 alphanumeric characters coded to the latitude and longitude of its image center. Characters 1-5 designated the latitude, 6-11 the longitude. The first character of each group is a letter, N or S for latitude and E or W for longitude, with the remaining characters being numerals designating degrees and minutes. For example, the ERTS image whose center coordinates are N43-19/W071-07 (NASA notation) would be encoded N4319W07107. This ID system is logical and uniquely identifies and locates any ERTS image worldwide. To allow quick human recognition, space for a name has been allocated in each ID field. Suitable names will be determined at a later time.

When completed, the current programming of the bisector ERTS scene format will allow a worldwide computation of format coordinates. The next step will be computer Calcomp plotting of scenes with their ID numbers and names on any desired standard map projection.

J W Schoonmaker Jr.
James W. Schoonmaker, Jr.

ERTS Images at 45° Latitude

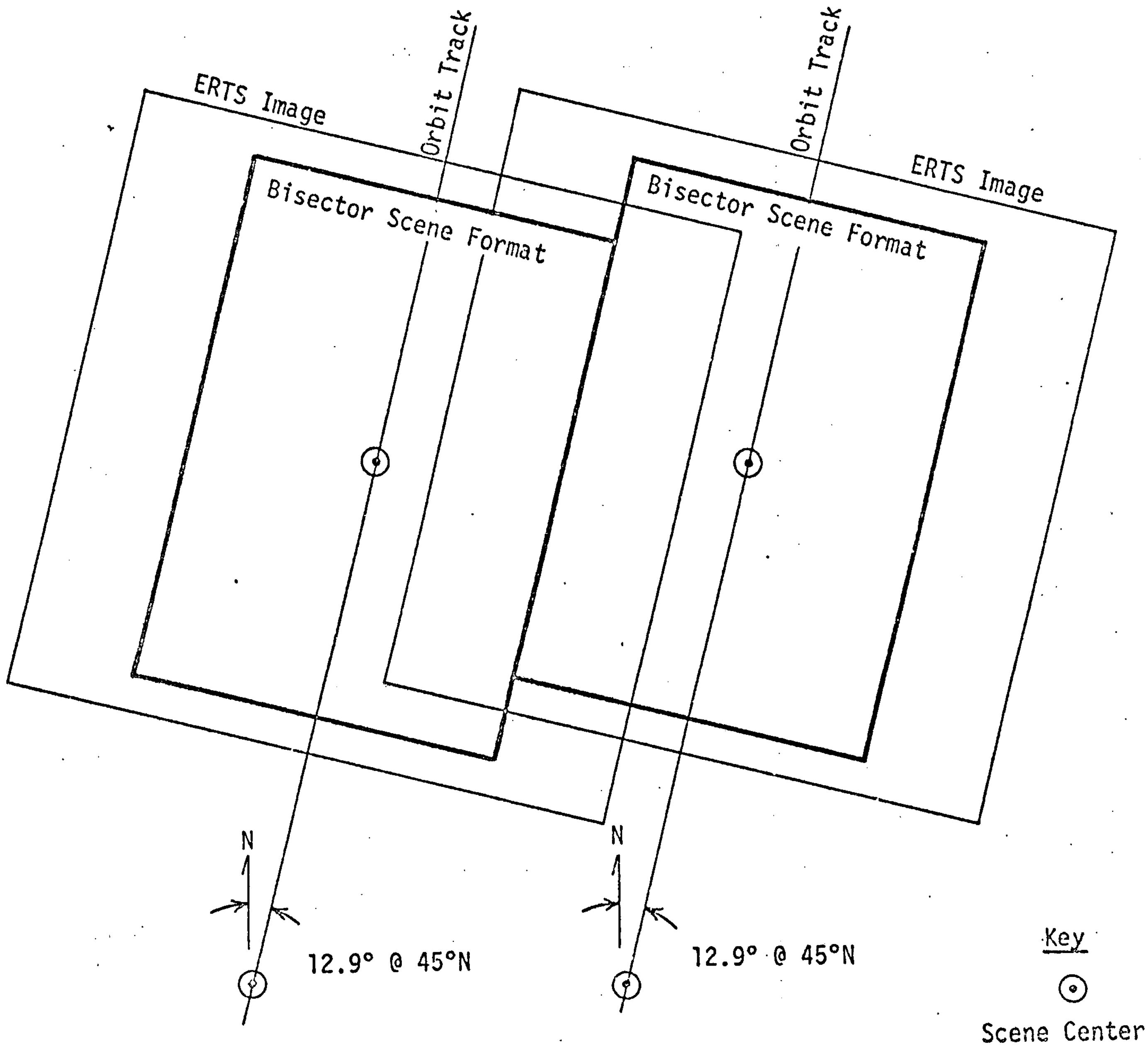


Figure 1

PROGRESS IN CARTOGRAPHY, EROS PROGRAM

Alden P. Colvocoresses and Robert B. McEwen
U.S. Geological Survey
Topographic Division
Washington, D.C. 20244

1973

PROGRESS IN CARTOGRAPHY, EROS PROGRAM

by
Alden P. Colvocoresses and Robert B. McEwen

INTRODUCTION

During the past 7 years the Interior Department EROS (Earth Resources Observation Systems) program with NASA sponsorship has conducted cartographic research based on high-altitude aerial and space photographs. The research has centered on the direct use of the image and its transformation into so-called photo or image maps. Today the cartographers of the Geological Survey have a real opportunity to apply themselves to making maps from data supplied by a satellite which is dedicated to remote sensing of the Earth.

On July 23, 1972, ERTS-1 (Earth Resources Technology Satellite; the figure 1 indicates the first of a series of proposed flights) was successfully launched into orbit by NASA. Within a few days its Return Beam Vidicon (RBV) cameras and Multispectral Scanner (MSS) were transmitting scenes of the Earth. The RBV cameras were turned off early in the mission because of technical problems in the control system, but the MSS continues to perform nearly flawlessly. The RBV cameras may be turned on again in the future. Two basic products are produced by NASA (Goddard Space Flight Center) from ERTS-1, which are known as bulk (system-corrected) and precision (scene-corrected) imagery. Bulk and precision processing are applied to both RBV and MSS imagery, and since there are three RBV spectral bands and four MSS bands, a variety of image forms can be produced for any one scene. NASA provides transparencies and/or prints at 1:3,369,000 and 1:1,000,000 scale to investigators and cognizant government agencies. The Interior Department, through the EROS Data Center at Sioux Falls, S. Dak., sells ERTS-products to the public at nominal cost. ERTS-1 is scheduled to remain in orbit for a full year, but with good luck its effective life may be much longer.

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Cartographers of the Geological Survey have developed a number of ERTS-1 experiments, accepted by NASA, as follows:

Experiment	NASA Proposal
• Photomapping of the U.S.	211
• Map revision	237
• Basic thematic mapping	116
• Polar regions mapping	149
• Mapping from orbital data	150
• Overall cartographic application	233

The principal investigators for these experiments are receiving a wide variety of imagery; in addition, NASA has asked them to take a quick look at selected ERTS-1 imagery and report preliminary findings. The cartographic experiments are unique in that they apply to the development of graphics related to an accepted reference figure of the Earth to some defined degree of accuracy. However, both geometric and perceptional considerations are involved. Although the revision of line maps by means of ERTS materials is one of the more important experiments, the others concentrate on the problem of turning out maps in which the image itself provides the base.

PERCEPTIONAL CONSIDERATIONS

Maps are expected to have an informational content commensurate with their scale. For image-based products, which go under the general name of photomaps, image quality must be adequate for the map user to perceive (detect) and, within reason, identify objects that imagery of the given scale can be expected to portray. Cartographic products are normally lithographed and viewed by the unaided eye, a condition that establishes criteria for the evaluation of the perceptional quality of a photomap. Line maps, on the other hand, are highly interpreted products on which important features are shown and identified regardless of whether they can be seen or identified in imagery of the same scale. For example, major roads and railroads appear on most general-purpose maps of small scale (say 1:1,000,000), but the images of the features are not usually visible at the same scale.

The informational content of an image is based primarily on two factors, spectral and spatial response. Spectral response is measured by monochromatic tone or color differences, and the term *spectral consistency* is used here for evaluation of ERTS imaging forms in relative terms of repetitive spectral response. Line maps are normally compiled from black-and-white aerial photographs in which objects are defined by differences in density, recorded as tones of gray. As long as the density differences enable the map compiler to detect and identify the mappable object, spectral consistency is not of primary concern. But photomaps, which use the image as a base, are highly dependent on the spectral consistency of the image. Since spectral response changes with time, sun angle, and atmospheric conditions, the production of photomaps which normally incorporate more than one image poses a real problem in attaining spectral consistency. The problem is magnified when the parameter of color is introduced, for now one must deal with three spectral responses (normally) rather than one. Automated thematic mapping--or Autographic Theme Extraction, as it is called in the Geological Survey--is based on image density slicing, and here again spectral consistency is the key.

Spatial response is measured by the minimum size of objects (of uniform response) that are uniquely recorded under certain conditions and can be identified as real scene objects rather than system noise. The term *object detectability* is used here to evaluate ERTS forms for spatial response. The term *resolution* is normally employed as a measure of spatial response for photographic products, but it relates to the minimum observable spacing between two like objects, such as stars in the sky or targets on the ground. With electro-optical systems such as TV or optical scanners, the relationship between resolution and minimum object size (detectability) is different than with photographic systems. Object detectability depends on edge sharpness or acutance as well as resolution, and the term is used in preference to resolution even though methods of quantifying detectability are not fully developed. (Rosenberg, 1971.) Both spectral consistency and object detectability are related to recorded contrast, which in turn depends on the differences in spectral response, atmospheric conditions, and image processing.

The following table evaluates the various types of ERTS imagery with respect to spectral consistency and object detectability and also indicates maximum practical printing scales for the imagery:

Perceptional Relative Image Quality

Image type	Spectral consistency	Object detectability	Maximum printing scale
RBV bulk	Poor to fair	Good	1:500,000
MSS bulk	Good	Good	1:250,000
RBV precision	Poor to fair	Fair	1:500,000-1:1,000,000
MSS precision	Poor to fair	Fair	1:500,000

We acknowledge that many ERTS-1 images have particular features that can be effectively enlarged to scales of 1:100,000 or larger; high-contrast land-water interfaces are good examples. On the other hand, objects of equal size but lower contrast become indistinguishable at the larger scales. Therefore, the maximum printing scales are rated as appropriate for maximum information content as viewed by a normal unaided eye at reading distance.

Resolution would also be a useful indicator of image quality, and the Geological Survey has asked NASA to install sizable targets on the ground for definitive resolution analysis. In the meantime, image edge analyses and similar techniques are being applied, but it is not known how well they can relate to resolution as photographically recorded in terms of target response.

The table given above is significant in that only one type, MSS bulk, exhibits image quality (perceptional) suitable for 1:250,000-scale mapping. However, conclusions about map products should not be drawn until the geometric properties have been fully examined.

GEOMETRIC CONSIDERATIONS

A major goal of the Interior Department is to map the country at various scales and with accuracy as defined by the U.S. National Map Accuracy Standards (NMAS). For planimetry the standards require, in effect, that 90% of well-defined features should be in error by no more than 0.02 inch (0.5 mm), measured on the publication scale. The 90% accuracy value is therefore $\sim$500 m (on the ground) at 1:1,000,000 scale, $\sim$250 m at 1:500,000, and $\sim$125 m at 1:250,000. Map errors may not be normally distributed, but for practical purposes the root mean square (rms) error of position for points tested should be less than 300 m at 1:1,000,000 scale, 150 m at 1:500,000, and 75 m at 1:250,000 scale to meet NMAS. Until recently it was considered impractical (or impossible) to make maps of scales smaller than $\sim$1:100,000 that met or even approached NMAS because oversize symbolization of features and other cartographic treatments require sizable positional displacement on small-scale maps. Photomaps, unless extensively annotated, do not contain displacement due to symbolization, and there is no reason why a photomap of small scale cannot meet NMAS as long as the image is geometrically sound and adequate control is available.

A prime consideration in attaining or analyzing map accuracy is the internal geometry of the imaging system. The desirable image is one that has a minimum of internal distortion. The ERTS image data processing system has unique capability, in the computer processing and electron beam recording, to system-correct many distortions. If the system were stable and if all sensor distortions and spacecraft motions were completely calibrated, the result could be an image of high internal geometric quality. At present, good calibration is available for the RBV system, and a mathematical model of the distortions has been developed (Wong, 1972). The MSS system is not suited to similar calibration, and moreover it fully incorporates (in the recorded image) the effects of small but continuous attitude changes of the spacecraft.

The available RBV frames, though limited in number, are enough for comparison of the reseau coordinates with calibrated preflight values. At ground scale the internal distortion ranges from a minimum of 42 m to a maximum of 100 m on the images evaluated. The average rms distortion for all RBV images is 65 m and is generally a random distribution, representing images of high geometric quality and probably the practical limit for the ERTS RBV. The figures cited represent only the internal distortions of the sensor system. In practice, internal sensor distortions are combined with external distortions, such as topographic relief, earth curvature, sensor attitude, and the map projection. External distortions have been previously analyzed (Colvocoresses, 1970). When control-point image coordinates are compared with map coordinates, both external and internal distortions are effective, and the comparisons are true tests of images for mapping purposes.

Selected well-defined features on several RBV images have been compared with established Universal Transverse Mercator (UTM) coordinates. The number of points has been densified at selected sites to 15 or 20 points per image. The ability of an observer to identify and measure a ground control point varies, but for well-defined points it is between 15 and 25 m. The tested RBV frames fit the UTM coordinates with a maximum rms error of position of 150 m and a minimum of 100 m, determined by a least-squares four-parameter fit using x and y translation, rotation, and scale change. Additional adjustment allowing for tilt rectification produced a slight improvement but, as expected with a near-vertical, narrow-angle system, not enough to justify additional processing.

Many more MSS images have been measured and compared with ground control points. The MSS does not have a reseau, and preflight calibration data are not available. Since the internal and external errors cannot be separated, the only approach is to measure image points and attempt to identify and isolate specific errors. The MSS image is subject to certain microdistortions or anomalies that occur at regular intervals. In addition, some images have lines obviously omitted or displaced during processing. One anomaly is illustrated in figure 1, which is derived from a 1:100,000-scale enlargement of the Golden Gate bridge obtained from frame 1021-18172-6. The stair-step pattern is apparent; it follows a periodic cycle of 6 lines or one mirror scan. The offset is a function of the angle between the scan lines and the feature and may amount to over 100 m. The anomaly can be observed on airport runways, coastlines, and other linear features in other frames. NASA has recently indicated that the anomaly is one that they believe can be eliminated, or at least reduced, and that corrective action will be undertaken.

Early MMS images fitted to ground control had rms distortions up to 1000 m, always larger than 300 m. Best results to date were obtained with frame 1080-15192-5, showing Chesapeake Bay. Figure 2 shows a vector plot of residuals for that frame, for which rms = 192 m. Systematic error, such as changes in mirror speed and spacecraft attitude, can be corrected, so that MSS geometric quality can be further improved.

Measurements have been made on 70-mm third-generation and 24-cm (9.5-in.) fourth-generation transparencies. Some first-generation images were also measured, with results identical with those obtained with a third-generation copy of the same scene. It does not appear that image duplication, enlargement, or processing is introducing any significant distortion even though target scales, such as 1:1,000,000, may not be exact.

Separate spectral bands of the same MSS scene have been measured and compared. The results indicate excellent register between bands, with maximum differences of only 10 to 20 m. Multispectral analysis of a single MSS scene is therefore subject to a negligible geometric error.

The bulk-image scenes are positioned by orbital data. The latitude and longitude coordinates for the midpoint of the scene given in the data block are subject to some errors, as are those for the edges of the frame. Frame 1080-15192 of Chesapeake Bay has center coordinates approximately 5 km in error. Some frames may have greater errors, but scenes processed since November 1972 are reported to be of better accuracy. However, sequential scenes cannot be registered by reference to indicated positions.

Both bulk and precision images of scene 1002-18131, Lake Tahoe, have been evaluated for geometric accuracy. The scene is available in all seven bands from the RBV and MSS and is the only one for which measurements have been made on precision-processed products. The measurements indicate an rms of 140 m for the RBV (precision) and 170 m for the MSS (precision). Since the scene was the first so processed and included unusual problems relative to terrain and control, the indicated rms values are considered to be high. The following summary contains a somewhat lower range of expected values and is based on the finding that most bulk images measured have exhibited less distortion than the Lake Tahoe scene.

Summary of expected image distortion
after best fit to ground control

Type	Error (rms, in meters)
RBV bulk	100-150
MSS bulk	200-450
RBV precision	100-150
MSS precision	100-150

Relating scales to errors through the NMAS, we might assume from the tabulated errors that maps of 1:500,000 scale could be made from RBV bulk, RBV precision, and MSS precision images whereas 1:1,000,000 would be the largest acceptable scale for MSS bulk. If the indicated errors were purely random, the deductions would probably hold, but systematic error is present and accuracy can be improved in cartographic processing. Specifically, it should be possible to improve the geometry of the bulk imagery through application of corrections determined from control-point comparison in precision processing. The procedure requires individual computations for each scene as well as a second printing with the electron beam recorder. NASA is not yet prepared to undertake custom processing routinely, but has indicated that engineering tests of the concept will be undertaken. If the evidence indicates that custom processing will reduce distortion in bulk MSS imagery to perhaps half of present values, processing of ERTS imagery may be eventually modified to incorporate these geometric corrections.

However, it should also be noted that some types of cartographic products do not need to meet NMAS but may be useful even though their rms error is about twice the allowable NMAS error. Nevertheless, the basic conflict between perceptional and geometric qualities of the ERTS RBV and MSS images poses a real challenge to the mapmaker.

ANALYSIS OF THE MAPPING PROBLEM

With ERTS imagery, the mapping problem can be divided into two distinct categories, depending on whether identifiable ground control is or is not available. For the better mapped areas of the world, such as Europe and the United States, photoidentifiable control is readily available and permits the precise geometric evaluation and fitting of ERTS imagery to the Earth's figure. It also provides the basis for NASA's precision processing, in which the image is transformed and fitted to a recognized (UTM) map projection. In areas where ground control is not available, mapping must depend on orbital (and sensor) data by methods and techniques that are the subject of a specific ERTS investigation that is still in its early stages. The image of an RBV is a perspective projection, like the image of a conventional frame camera, and therefore mapping with RBV imagery by reference to either ground control or orbital data is a matter of well-understood, established procedures. The MSS, an optical scanner, creates a continuous image made up of a large number of independent picture elements (pixels), each representing a small segment of the Earth's surface. If printed out in raw form, the image would have such complex geometry that the mapmaker would find it all but impossible to use. To overcome the problem, NASA applies no less than 14 geometric corrections to the MSS imagery (noted on page G-18 of the ERTS Data Users Handbook prepared by General Electric for NASA). The curved Earth surface cannot be depicted on a plane without some distortion, but since the MSS image ray is always within 5.78° of the nominal vertical and the curvature of the Earth across the scene is less than 2°, the image approximates an orthographic view. The printed MSS image is a montage of sequentially produced thin projections and therefore lacks the internal geometric fidelity of the instantaneous frame image of an RBV. (See table of distortions presented earlier.)

Precision processing was defined as a system that correlates ERTS imagery to photoidentifiable ground control, rescans the image, and fits it to a specified projection. Unfortunately, precision processing involves considerable degradation of image quality that limits its application although the geometric improvement of the MSS imagery is highly significant for the mapmaker.

Regardless of availability of identifiable control and type of image used, the problem of map format is critical. The simplest format is that of a single ERTS scene whereas conventional geographic quadrilaterals or States normally require a mosaic made from several scenes. Using single scenes is relatively simple, and producing cartographic products from them is referred to as *First Phase Mapping*. Producing standard quads or State base maps is far more complex and is referred to as *Second Phase Mapping*.

FIRST PHASE MAPPING--IMAGE OR SCENE FORMAT

The first phase involves the processing of a single ERTS scene which by any of three methods has been brought to a specific scale and form and related to the figure of the Earth. Mapmakers are loath to use an image to define map boundaries, but in the case of ERTS the scenes are of sufficient size and repeatability for use in defining a series of maps. (The extent to which the system will be accepted by map users is not known.) The three methods of processing a single scene are as follows:

- Precision processing by NASA, which applies geographic (latitude and longitude) or plane coordinate (UTM) ticks to the image as transformed to the UTM projection. An agency such as USGS can then add a fine-line grid and lithograph in either black-and-white or color. The orthophotoimage of Lake Tahoe reproduced in color is a sample product; 1:1,000,000 is the only publication scale used to date, and the precision processing imposes image-quality limitations that may preclude publication at large scales. It is important to note that any ERTS image precision processed by NASA is a cartographic product. Suitable control throughout the U.S. is being identified by the U.S. Geological Survey and furnished NASA. The precision-processed images so far produced of the U.S. do meet NMAS at the 1:1,000,000 scale, and accuracy can undoubtedly be maintained wherever suitable control is available.

- A bulk ERTS MSS image can be rectified and scaled to a defined projection and a geodetic grid. At 1:1,000,000 scale the products should meet NMAS, but at 1:500,000 the error may be about twice the tolerance of NMAS. An RBV bulk image should meet NMAS at 1:500,000 and still present an image of acceptable quality in monochromatic printing.

- The third method is to bring an ERTS image as close as possible to a predetermined scale and fit a grid that has been generated from image-identified control points. The grid-fitting method is particularly applicable to bulk MSS imagery, and the products should meet NMAS at 1:500,000 scale. It should be noted that the image has not been controlled to an accepted map projection and the grid lines theoretically do not form perfect squares. However, the departure from the perfect square is so small that it is not measurable in individual grid units. At present, this procedure is the only one of the three that promises to produce a 1:500,000-scale map of good image quality at NMAS.

SECOND PHASE--QUADRANGLE OR STATE FORMAT

A 1:250,000-scale standard geographic quad extends 1° in latitude by 2° in longitude and may be covered by only 2 ERTS scenes. A 1:1,000,000-scale quad extends 4° in latitude by 6° in longitude and may contain 30 or 40 ERTS scenes. USGS 1:500,000-scale maps are now State maps rather than quadrangle maps, and therefore vary greatly in size and shape. Second phase maps at 1:250,000, 1:500,000, and 1:1,000,000 are in various stages of compilation; we hope that they will be lithographed and placed on public sale by USGS in the near future.

APPLICATIONS AND FINAL FORM

There are several cartographic applications of ERTS imagery. Revising line maps is one in which the image is not retained, but the other applications defined to date retain the image or a derivative of the image as follows:

- *Monochromatic orthophoto.*--normally derived from one spectral band and portrayed in gray tones. Colors may be assigned as a function of density, but the basic input at some stage is a single gray-tone image.

- *Polychromatic orthophoto.*--the color image application; with ERTS, normally gives a false-color rendition that includes the near-infrared.

- *Autographic theme extraction.*--a derivative application that isolates one or more basic themes, such as water, snow and ice, or infrared reflective vegetation.

Final form depends on the reproduction process used and results in photographic, diazo, or lithographic prints. The choice of final form is generally determined by the expected demand. However, diazo is now limited to a single color whereas the photo and lithographic form may be either in black-and-white or in color.

At this stage of investigation, it is impossible to say what combinations of the characteristics described will result in optimum products. All indications are that out of ERTS will develop one or more series of maps that will be of real value to this country and to the world as a whole.

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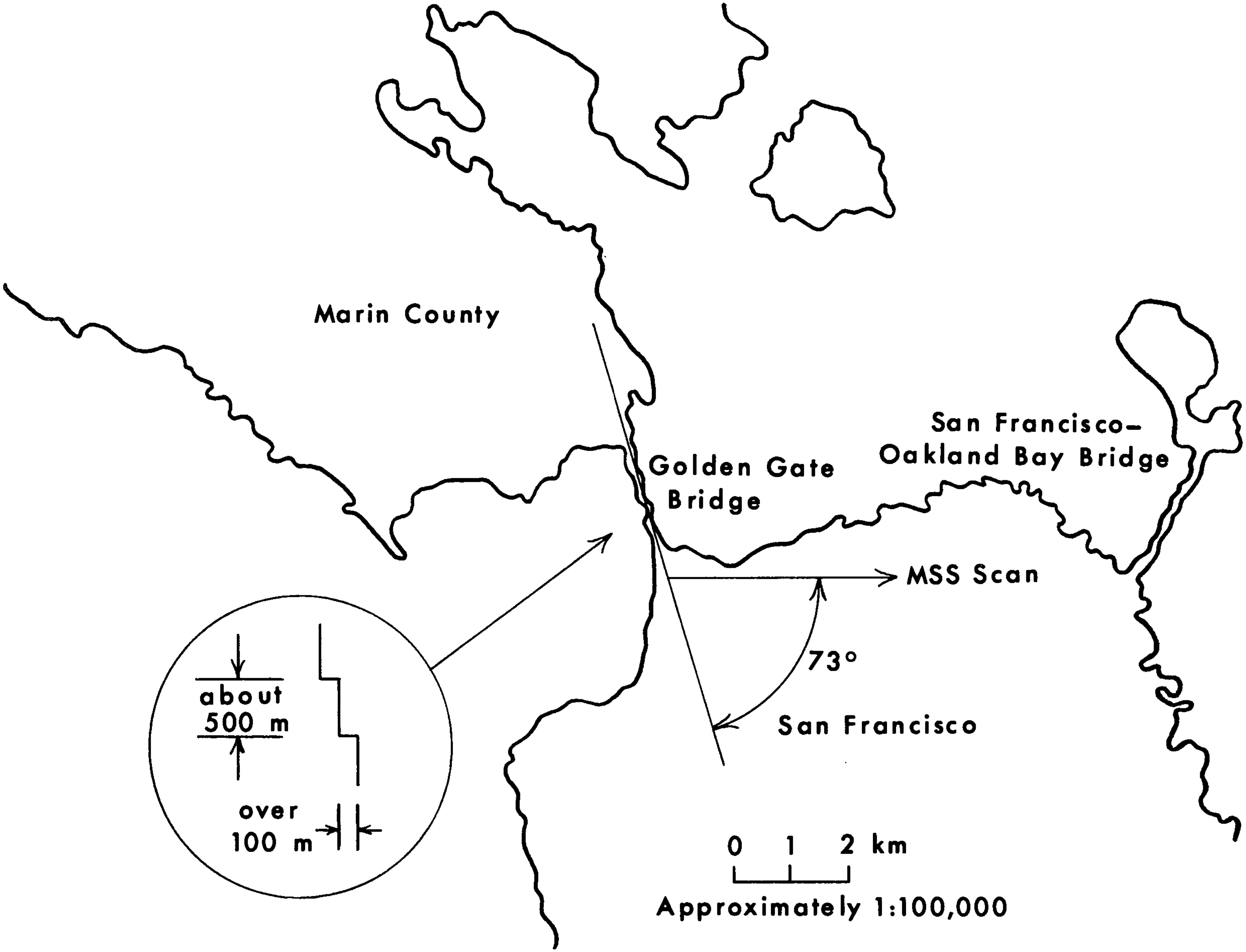

Figure 1. -- MSS line-scan anomaly.

Note: Image coordinates fit to UTM coordinates using four parameters: X and Y translation, rotation, and scale. Error (rms) for this band is 192 m; average for the 4 bands of this scene is 210 m.

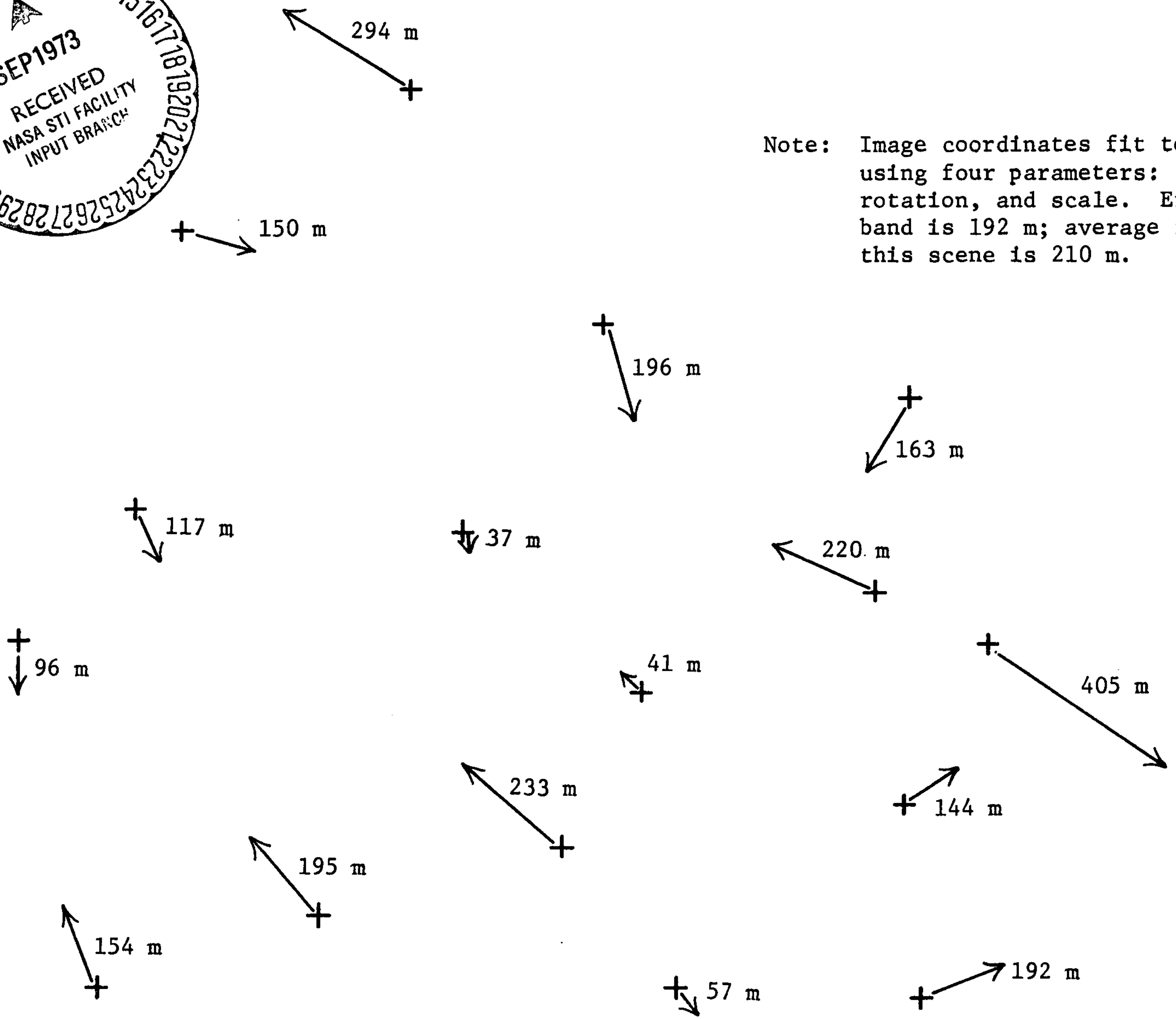

Figure 2.--MSS bulk-image distortion (meters); frame 1080-15192-5, Chesapeake Bay area.

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