Paper L 15

TOWARDS AN OPERATIONAL ERTS - REQUIREMENTS FOR IMPLEMENTING CARTOGRAPHIC APPLICATIONS OF AN OPERATIONAL ERTS TYPE SATELLITE

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Background

After nearly 18 months of successful operation of the first Earth Resources Technology Satellite (ERTS-1), a careful look at the future is obviously in order. Judging from the results of ERTS-1 experiments, public sales of ERTS-1 products and overall worldwide response it is believed that ERTS-1 has demonstrated an Earth sensing mode that should become operational. It is recognized that several studies leading to the definition of an operational ERTS have been made. However cartographic requirements are generally more basic and demanding than those of the Earth science disciplines and are therefore treated separately in this paper. One assumption made is that the configuration of ERTS, particularly with respect to the Multispectral Scanner (MSS) and data transmission rates cannot be materially altered.

General

Although the ERTS-1 experiment was not designed for mapping applications, cartographers (foreign as well as domestic) have examined and evaluated ERTS-1 imagery. The consensus of these investigators is that an operational ERTS-type satellite can have many valuable applications, particularly where the image itself serves as the cartographic base for medium- and small-scale maps. The requirements for implementing these applications are based on capabilities as demonstrated by ERTS-1 or as defined for a future ERTS-type satellite as follows:

- Continuous operation which, subject to visibility, covers the earth from 82° N to 82° S every 18 days.
- Near-real-time reception of data.
- Near orthogonal imagery (ERTS-1 has a maximum angle off axis of only 5.76°).
- Geometric fidelity, which permits accurate positioning at scales as large as 1:250,000.

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- Spatial frequency (resolution) commensurate with an instantaneous field of view in the 40- to 80-meter range.

- Radiometric fidelity in several simultaneously acquired wavebands including the near infrared.

Spatial Frequency

Requirement - Image quality suitable for detection and identification of image control points and major planimetric features, such as roads, railroads, canals, field boundaries, urban boundaries, and water-land interfaces.

Rationale - Need to produce imagery suitable for reproduction at scales as large as 1:250,000 - a standard medium scale accepted throughout the world. Much useful information for many disciplines can be derived from these products and be referenced to the figure of the earth.

Present Performance - Instantaneous field of view (IFOV) of MSS is a 79-m square and the recorded net pixel is 79 by 59 m. The Return Beam Vidicon (RBV) line width is equivalent to 45 m and theoretically should produce the higher resolution, although empirical tests to date have not borne this out; the RBV is rated equivalent to the MSS with an effective pixel size of about 80 m.

Changes - To obtain the image quality required for more useful cartographic products, one relatively broad band of imagery (0.5 - 0.7 μm) should have an effective pixel size of about half the side dimension of that of the present sensors.

Suggested Solution - Increase (perhaps double) the focal length of the RBV(s), limit its response to one spectral band, and maintain the same width of coverage as the MSS. Considerable spatial frequency increase can be obtained before image motion compensation (IMC), which is a complex modification, would be needed. Current criteria for acceptable image motion is that the degradation along track should not exceed 50% of the cross track resolution. The existing 79 m IFOV would be suitable for the MSS bands.

Spectral Frequency

Requirement - Record a minimum of two bands in the visible and two in the near IR.

Rationale - These spectral bands are needed to differentiate fixed and temporal phenomena, such as cultural features, open water, areas of vegetation cover, snow and ice, topographic features, local atmospheric anomalies, and the various meaningful variations and combinations of these phenomena insofar as unique recordable spectral responses exist.

Present Performance - Two visible and two near IR bands are now recorded by the MSS. The three RBV bands provide redundancy to the four MSS bands.

Changes - None - except reduction of RBV bands from 3 to 1.

Temporal Frequency

Requirement - Near global coverage every 18 days.

Rationale - The frequency of repetitive coverage of ERTS-1, which promises to produce complete cloud-free coverage of the U.S. on an annual basis and coverage of selective representative areas on a seasonal or even monthly basis, is considered adequate except for monitoring short-lived phenomena. Increasing the number of satellites would increase frequency, but the cost of data acquisition and handling would probably negate this advantage. If short-lived phenomena are in fact to be monitored from space, a geosynchronous system capable of selective area coverage is believed to be the most feasible solution.

Present Performance - 18-day global coverage except for latitude higher than 82°.

Changes - None

Reception and Processing Time

Requirements - The conversion of selected sensor response into cartographic products in a matter of days - maximum of one week.

Rationale - Although ERTS is not considered suitable for the monitoring of short-lived phenomena, it does record certain items that should be rapidly disseminated in cartographic form. Examples involve the delineation of water boundaries which includes surface water distribution, flood conditions and the water-ice interface in polar regions. The seasonal delineation of infrared reflective vegetation is another.

Present Performance - Except for coverage of the eastern U.S. data tapes must be flown to Goddard for processing. Precision processing or otherwise relating imagery to ground control and preparing products for distribution now involves manual procedures which may take a month or so to accomplish. However, a single gridded ERTS product at 1:1,000,000 scale (Lake Tahoe) was brought to the reproduction stage in a matter of 15 days after acquisition.

Changes - Provide direct real time reception to the processing centers insofar as possible. For the U.S. a reception station in South Dakota and another in Alaska is suggested. Processing centers should be equipped to produce selected imagery in cartographic form (precisely referenced to the figure of the Earth) within a matter of 2 or 3 days after reception. By use of digital or optical density slicing certain of these signatures should be reduced to thematic binary form and thus simplify the processing.

Geometric Properties of Imagery

Requirements - Independent spatial positioning of imagery compatible with requirements for 1:1,000,000 scale and, with the benefit of ground control, for 1:250,000 scale at National Map Accuracy Standards (NMAS).

Rationale - An operational remote sensing system must not only record identifiable data but also have a means of spatial reference. An accepted system of reference is one that relates to the figure of the earth as described in spherical coordinates (lat/long) or plane coordinates (X Y). For remote areas, 1:1,000,000 scale is adequate for delineation and changes of gross features, but 1:250,000 scale is needed to portray changes to developed areas and indicate where more precise mapping is required. A 1:250,000-scale map that just meets NMAS contains root mean square (rms) errors of about 80 m. Thus accuracy and MSS pixel size would be of the same approximate size, which is a logical relationship.

Present Performance - Positioning of ERTS data with control only by orbital and sensor parameters (independent mapping) now involves errors in the order of 2,000 m (rms). This is compatible with maps of 1:6,000,000 scale. With the aid of ground control, a system-corrected (bulk) image when fitted to a conventional map projection involves errors of 200-450 m, which is marginal for 1:1,000,000-scale mapping. Fitting a geodetic grid to an MSS image reduces these errors to the 50 to 100 m range, which is compatible with 1:250,000-scale mapping. However this involves the use of the existing projection of the MSS image which is semiperspective and lacks the conformality of geodetic projections. Scene-corrected (precision processed) MSS imagery has errors in the 100- to 200-m range but because of degraded image quality is considered suitable for reproduction at no larger than 1:500,000 or possibly 1:1,000,000 scale. On a portion (1/16) of an MSS bulk image on which at least two control points can be identified, points which are part of a defined pattern (shore line, field lines, highways, etc.) can be located to within 20 to 30 m (like all other accuracy figures stated herein these are rms figures).

Changes - Increase the independent positioning capability from 1:6,000,000 (2,000 m) to 1:1,000,000 scale (300 m) if possible. Define the imaging system so that either bulk or precision images can be produced with less than 80 m error in areas where suitable control exists. All such imagery to retain the spatial frequency (quality) of the original data.

Suggested Solution - Slightly improve positional and attitude determination devices. Modify the system corrected (bulk) printing of MSS to a conformal (Space Oblique Mercator)* projection. For those who may not accept the

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*A description of this projection is contained in a memorandum (EC-18-ERTS) which is attached and made a part of this paper.

Space Oblique Mercator projection provisions for precision processing without loss of image quality and on a conventional projection such as the UTM should be provided. It is believed that demands for this product will be relatively small since the Space Oblique Mercator projection accommodates the conventional geodetic grids without measurable distortion and the precise relationship between the projections can be mathematically defined. In polar regions such precision processing would normally be on a polar stereographic projection. Incorporate one RBV band with maximum spatial frequency and an engineered reseau of approximately 30 points, most of which are near the image border.

Image Repeatability

Requirement - Hold successive images of the same scene to a maximum of ±13 km from the nominal scene center.

Rationale - An ERTS satellite system has the potential of repeating image positions to the indicated requirements. If accomplished, this would provide a worldwide system of formats based on the nominal scene with very high assurance that the formats will be completely covered by subsequent corresponding scenes. Such maps could be published in perhaps 1/10 the time and effort now required for conventional formats, which normally involves mosaicking images from several orbital passes. Use of the image format would permit publication and distribution of ERTS imagery in a timely and relatively inexpensive form.

Present ERTS Performance - The ERTS orbit is permitted to drift (cross-track direction) about ±15 km before corrections are made. Attitude variations produce up to ±11 km offsets. Thus the cross track maximum variation may be ±26 km whereas the minimum side lap at the equator is only 26 km or ±13 km. Along-track image boundaries are generally within ±5 km.

Changes - Hold orbital drift, attitude variation, and along-track image boundaries of the MSS so that the resultant scene has a maximum cross track deviation of ±13 km, and no more than ±5 km deviation in the along-track direction to a prescribed scene center point.

Suggested Solution - Improve orbital and attitude correction parameters and maintain standards for defining along-track image boundaries of the MSS.

Sensor Alignment

Requirement - Obtain a square MSS image format at the midlatitudes.

Rationale - Scanners and frame images should cover the same area. A square format is the more efficient to process and also is more esthetically pleasing.

Present Performance - MSS has a 3° nominal image skew at the midlatitudes--4° at the equator and 0° at maximum inclination (81°).

Changes - Define a nominally square image for the MSS at the midlatitudes.

Suggested Solution - Turn the spacecraft or sensors 3° to the right of the spacecraft velocity vector. This will create 1° skew at the equator, near 0° at the midlatitudes on the descending node, and 3° at the maximum inclination (82°) where it is of lessor concern.

Summary

The attached table summarizes the cartographic requirements for an operational ERTS type satellite.

CARTOGRAPHIC REQUIREMENTS FOR AN OPERATIONAL ERTS TYPE SATELLITE

Requirements	Rationale	Present Performance	Changes and Suggested Solution
Spatial Frequency 1 band 40 m pixel 4 bands 80 m IFOV	Identification of key cultural features Reproduction at 1:250,000 and smaller scales	80 m effective pixel size (RBV) 80 m IFOV (MSS)	Increase focal length of RBV and reduce to one band
Spectral Frequency 2 bands in visible 2 band in near IR 1 redundant RBV band (in visible)	Differentiation of fixed and temporal phenomena	2 bands in visible (MSS) 2 bands in near IR (MSS) 3 RBV bands redundant to MSS	Reduce RBV to 1 broader band
Temporal Frequency Near global coverage every 18 days	Optimum for this type of satellite system. ERTS orbit unsuited for detection of short-lived phenomena	Coverage every 18 days between N 82° and S 82°	No change
Reception and Processing Time Dist of selected data in cartographic form in 3 to 7 days	Time critical data must be in the hands of the user in a matter of days	Dist. of data (imagery) normally takes one to several months	Centralize reception and processing, provide for selective data processing in automated cartographic form
Geometry of Image Capable of 1:1,000,000-scale independent positioning. Capable of 1:250,000-scale positioning with control (all at NMAS)	1:1,000,000 is adequate for delineation of gross features and change thereto. 1:250,000 scale is needed to portray changes in developed areas and indicate where larger scale mapping is required	Capable of independent positioning at 1:6,000,000 NMAS. With control image can be fitted to 1:1,000,000 NMAS. Grid can be fitted to image of 1:250,000 scale. Scene corrected imagery meets 1:500,000 or 1:1,000,000 NMAS.	Improve positional and attitude determination to ±300 m (rms) Convert bulk image to conformal projection. All processing to retain original image quality. Use one RBV band of increased spatial frequency and engineered reseau
Image Repeatability Hold successive images of the same scene to ±13 km in the cross track direction and ±5 km in the along track direction with respect to the nominal scene center	The image format when repeated within stated limits becomes the basis for publication, it would involve perhaps 1/10 the time and effort of conventional quadrangle formats.	Orbit drift involves ±15 km, attitude variations ±11 km - both cross track, along track variations are within ±5 km	Hold cross track imagery variations to ±13 km, maintain along track image centers to ±5. Keep same nominal scenes as for ERTS-1

Requirements	Rationale	Present Performance	Changes and Suggested Solution
<u>Sensor Alignment</u> Nominal square format for MSS	Same coverage as RBV is needed. Square format is more efficient and esthetic	MSS has 3° nominal skew at midlatitudes	Skew spacecraft or sensors 3° to the right of the spacecraft velocity vector

United States Department of the Interior

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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 Space Cylindrical Strip Perspective: Space because it is defined and fixed in space, Cylindrical because of its shape, and Strip Perspective 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

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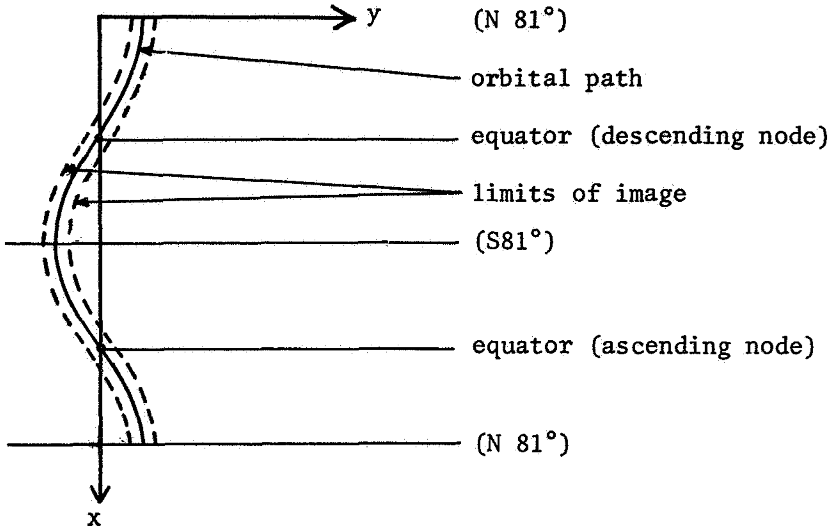
*By treating the projection plane as a cylinder (which is mathematically acceptable) the x values repeat themselves each orbit.

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-

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*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.

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References

1. NASA, Earth Resources Technology Satellite Data Users Handbook. Prepared and maintained by General Electric Corporation, 1971 - to date.

2. Konecny G., Geometric Aspects of Remote Sensing. Invited paper Commission IV International Congress of Photogrammetry, Ottawa, 1972.

3. Kratky, V., Cartographic Accuracy of ERTS Images, Proceedings of the American Society of Photogrammetry 30th Annual Meeting, March 1973, Washington, D.C.

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.

A.P.C. August 1, 1973

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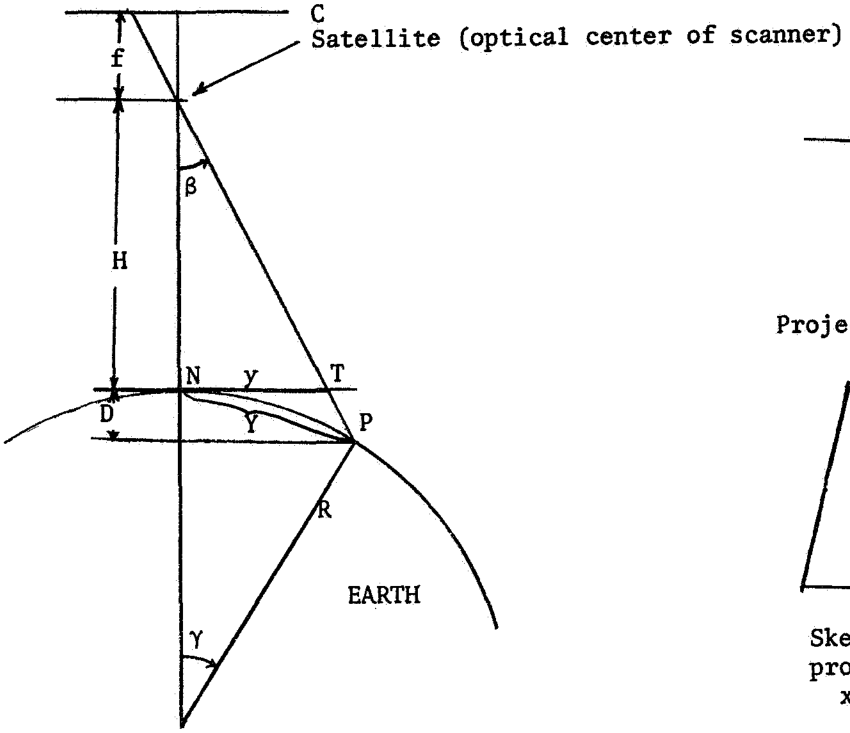
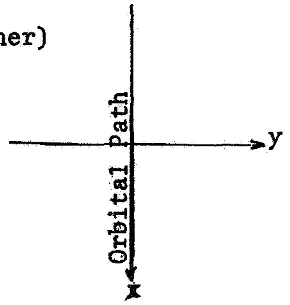
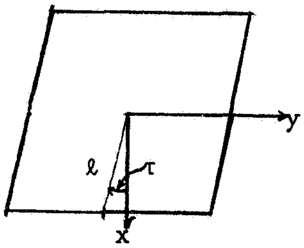
*All figures given are approximations. NASA is expected to make available exact figures which might be required for rigorous computations.

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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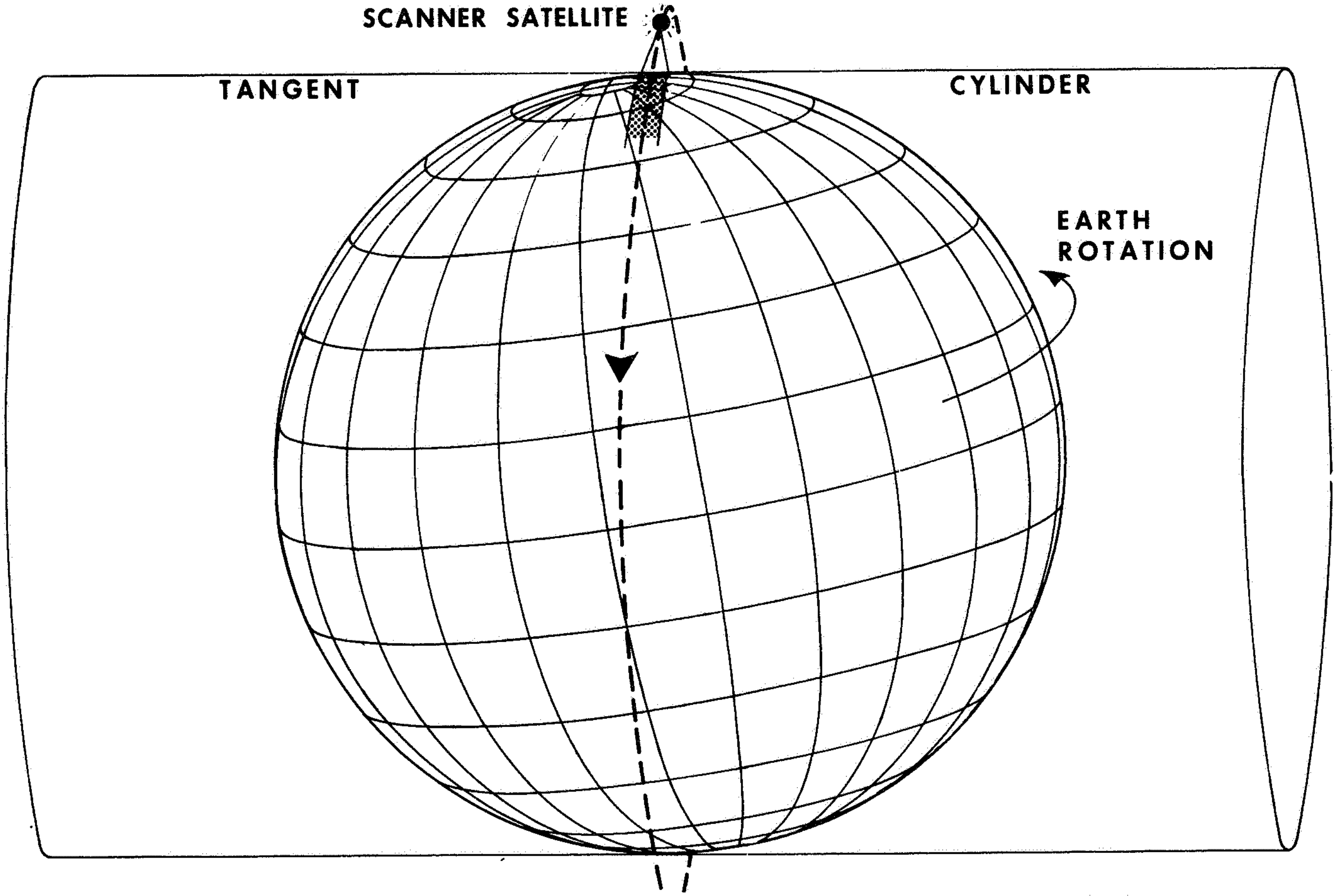
*If one disregards the small error introduced by earth rotation during the scan sweep (The maximum displacement in the x direction is only about 200 m for the 185 km scan length), the y direction on the actual image is that of the scan lines (as now configured). However the x direction of the projection 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

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