NASA
National
Aeronautics and
Space
Administration

APPLICATIONS NOTICE

AN-OA-76-B

INPUTS REQUESTED FROM EARTH RESOURCES REMOTE SENSING DATA USERS REGARDING LANDSAT-C MISSION REQUIREMENTS AND DATA NEEDS

The NASA Office of Applications plans to launch the Landsat-C satellite in September 1977. This notice is to solicit inputs from prospective Landsat-C data users to aid NASA in defining Landsat-C mission and data requirements.* It is important that prospective Landsat-C data users respond to this notice since the information received will be used to assist in making decisions regarding the scheduling of satellite operations and ground data processing operations.

The general objectives of the overall Landsat Project are to develop, fabricate, test and launch remote sensing satellites into medium altitude, sun synchronous orbits and to operate them and evaluate the contributions which the resulting data can make to a wide range of earth resources disciplines. The program includes the processing and distributing of data in useful form and on a timely basis.

*This is not a solicitation for data use investigations. It is anticipated that an Announcement of Opportunity for a small Landsat-C investigation program will be released in late 1976. As planned, that program will include the following changes from previous investigation programs: 1) fewer investigations; 2) emphasis confined to the development of information from the data provided by the improved Landsat-C sensors; 3) data purchased by the investigators from the appropriate public data centers (such as the Sioux Falls, South Dakota data center in the U. S., and the Brazilian, Canadian and Italian centers outside the U. S.).

(NASA-TM-X-73007) INPUTS REQUESTED FROM EARTH RESOURCES REMOTE SENSING DATA USERS REGARDING LANDSAT-C MISSION REQUIREMENTS AND DATA NEEDS (NASA) 27 p HC $4.00 CSCL 08B

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The general objective of the Landsat-C Project will be to extend the period of space-data acquisition for earth resources applications initiated by Landsat-1 and continued by Landsat-2, and to improve the spectral observing capability with the addition of a thermal IR channel, providing inter-comparisons of thermal data with simultaneous measurements at visible and near infrared wavelengths. In addition to the spectral imagery, an improved Return Beam Vidicon (RBV) system will provide high-resolution (40 meter) panchromatic imagery. The RBV data may be used independently or in conjunction with the lower resolution spectral data from the MSS to provide increased information content. The capability to relay data from remote land-based sensors will be continued by the Data Collection System on Landsat-C.

The specific primary objectives of the Landsat-C mission are as follows:

- o Continued acquisition and complete coverage of the United States with (1) multispectral 80 meter resolution images in reflected solar radiation; (2) 240 meter resolution images in emitted terrestrial infrared radiation; and (3) 40 meter resolution panchromatic images.

- o Continued acquisition of selected foreign coverage as determined by U. S. programmatic requirements and international arrangements either in real time using ground data readout stations or by use of the on-board tape recorders.

In connection with these primary objectives, it is expected that the data will be applied to research and operational demonstrations in such areas as agriculture, mineral resources, geography, water resources, environment and marine resources. Examples of such applications are land cover classifications for various applications; determination of factors relating to stress on crops and forests; inventories of crops, forests and range lands; classification of areas by geological or geomorphic characteristics; delineation of promising areas for mineral exploration; determination of water run-off patterns, flood plain boundaries, extent of snow cover, and flood mapping; acquisition of census-type information (demography); environmental impact assessment; shallow water bathymetry; and mapping of man-made surface alterations such as surface mining.

NASA is developing an all-digital processing system which should be operational in 1977 in time for the Landsat-C launch. The advantages of this system are that it will have the capability to produce approximately 200 digital scenes per day as opposed to the present capability of about 20 digital scenes, geometric corrections will be applied to the CCT data as well as to the imagery, data will be processed at the Goddard Space Flight Center in 24-48 hours as opposed to the two-three week period it takes now, and temporally registered digital data will be produced where adequate ground control points are available.

The Geological Survey's EROS Data Center (EDC) in Sioux Falls, South Dakota is the only data distribution facility which is planning at present to upgrade its system to interface with the new digital system at Goddard. Since data will not be provided directly to users by the Goddard Space Flight Center, users will have to order data from the EDC.

As of this date, the EDC data production system has not been completely defined, Consequently, it will not be possible to state exactly what kind of products will be available until the August-September 1976 period. It seems likely, however, that one of two alternatives will be chosen depending on available resources:

Alternative 1:

- o imagery data produced by the cubic convolution resampling algorithm in the Space Oblique Mercator (SOM) projection (Landsat imagery is presently being produced in the SOM projection).

- o digital data resampled using the cubic convolution technique and produced in the Space Oblique Mercator format.

- o digital data resampled using other algorithms and in other projections or unresampled data may be available at some additional cost pending final definition of the EDC system.

Alternative 2:

- o imagery data produced by the cubic convolution resampling algorithm in the SOM projection (same as in Alternative 1).

- o digital data available only in the cubic convolution resampled, Space Oblique Mercator format.*

The Landsat-C payload is described in Attachment 'A' to this notice. Present plans for data acquisition operations are stated in Attachment 'B'. Attachment 'C' gives additional information on data products. Attachment 'D' gives additional information on the cubic convolution resampling method, and Attachment 'E' provides additional detail on the Space Oblique Mercator projection.

Inputs to NASA in response to this Applications Notice should be submitted in letter form from all prospective users and should contain the following information:

a. Name, address, and organizational affiliation.

b. A statement of the nature of your interest in Landsat-C data with a description of the projected work to be performed. An indication should be given as to whether the intended use is considered operational in nature, a quasi-operational test of previously developed techniques, or research, etc. It would be helpful if user groups could be specified.

c. An estimate of Landsat-C coverage requirements such as geographical areas, time periods, frequency of coverage and cloud cover.

d. An indication of sensor requirements such as all bands of MSS, thermal or visible band data only, daytime versus nightime coverage, frequency of RBV coverage required relative to MSS coverage, etc.

e. An estimate of the type and amount of data required.

*Please note that if this alternative is selected (which provides only cubic convolution resampled data in the SOM projection), then the user can perform the radiance-dependent analyses on the data in this projection. Conversion of the data by the user into another projection (if required) can be done after the performance of the analysis, thereby avoiding conducting the analysis with degraded data. Comments on this technique, the cubic convolution resampling technique and the SOM projection would be appreciated in answering question "e" above.

Letters from U. S. sources should be addressed to:

Dr. Stanley C. Freden
Missions Utilization Office
Code 902
Goddard Space Flight Center
Greenbelt, MD 20771

with a copy to:

Mr. James R. Morrison
Office of Applications
Code ERR
National Aeronautics and Space Administration
Washington, DC 20546

Letters from individuals or organizations from outside the U. S. should be submitted in the same format. They should be typewritten in English and sent directly to:

National Aeronautics and Space Administration
Office of International Affairs
Code I
Washington, DC 20546

Copies should be sent to the two addresses indicated above (Dr. Freden and Mr. Morrison).

To ensure that adequate time is available to aggregate your inputs into the operational procedures, information should be received by NASA on or before September 1, 1976.

If you have any questions regarding this notice, please direct them to Dr. Freden at the above address or by telephone at (301) 982-5818.

Leonard Jaffe
Acting Associate Administrator
for Applications

Attachment A

DESIGN SPECIFICATIONS

LANDSAT-C

Landsat-C is the third mission in a program to develop and maintain global satellite coverage in the earth resources disciplines for a variety of users.

The Landsat-C observatory is an earth pointing stabilized spacecraft consisting of integrated subsystems that provide the power, environment, orbit maintenance, attitude control and information flow required to support the payload for a period of at least one year in orbit. It weighs approximately 960 kilograms (2116 pounds) and has an approximate overall height of 3.04 meters (10 feet) and a diameter of 1.52 meters (5 feet), with solar paddles extending out to a total of 3.96 meters (13 feet).

The sensors selected for this mission are the five-band Multispectral Scanner (MSS), the two-camera Return Beam Vidicon (RBV), and the Data Collection System (DCS) receiver and transmitter. The MSS images the surface of the earth in several spectral bands simultaneously through the same optical system. The MSS for Landsat-C has four bands operating in the reflected solar spectral region from 0.5 to 1.1 micrometer wavelength, and a fifth band from 10.4 to 12.6 micrometers in the emitted infrared range. It scans cross-track swaths of 185 kilometers (100 n.m.) width simultaneously imaging six scan lines across in each of the first four spectral bands and two lines in the fifth band.

The MSS is used on all three missions; for the first two (Landsat-1 and 2), the four spectral bands have been designated bands 4, 5, 6 and 7 (the multispectral RBV bands were designated bands 1, 2 and 3).

For the Landsat-C mission, a fifth band (band 8) 10.4 to 12.6 micrometers, is added in the thermal (emissive) spectral region. This band uses mercury-cadmium-telluride, long-wave IR detectors that are cooled to approximately 100°K by a passive radiation cooler. The dimensions that can be resolved in this band are about three times larger (240 m) than for bands 4 through 7. Energy is accepted through a slit near the fiber optics matrix and conducted by relay optics onto the detectors which form the field stops. The 5-band MSS has 26 video channels.

The Return Beam Vidicon (RBV) system for Landsat-C provides panchromatic earth images with nominally a factor of two improvement in ground resolution compared to the Landsat-1 and Landsat-2 multispectral RBV systems.

The ground resolution of the Landsat-1 and 2 RBV systems is nominally 80 meters. The increase in ground resolution to 40 meters is achieved by doubling the focal length of the lens system, halving the exposure time to reduce the effect of ground smearing, and removing the spectral filters, thus doubling the incoming energy to compensate for the faster exposure times.

The RBV system for Landsat-C contains two identical cameras that operate in the spectral band from .50 to .75 micrometers.

The two cameras are aligned to view adjacent nominal 98 km (53 n.m.) square ground scenes with a 14 km slidelap yielding a 183 x 98 km scene pair. Two successive scene pairs will nominally overlap each MSS frame. The four RBV scenes which nominally fill each MSS frame will be designated A, B, C and D.

The Data Collection System (DCS) provides the capability to relay and disseminate data collected by remotely located earth based sensors. The system involves remote Data Collection Platforms (DCP), satellite relay equipment, ground receiving site equipment, and a ground data handling system.

The DCP is connected to individual environmental sensors which are selected and provided by the user. The DCP transmits the sensor data, which are relayed to a ground receiving site through an on-board receiver/transmitter. In the U. S., the receiving site equipment decodes and formats the data for transmission to the Ground Data Handling System (GDHS) at Greenbelt, Maryland. In the Operations Control Center (OCC), the data are reformatted, written on magnetic tape, and passed to the NASA Image Processing Facility (NIPF) for further processing, then disseminated to the user agencies. DCS decoding equipment could be added to foreign Landsat receiving stations which would permit the use of the Landsat DCS system in areas outside North America. The DCS is designed to assure that the probability of receiving at least one valid message from any DCP every 12 hours is at least 0.95 for as many as 1,000 DCP's located throughout the United States.

MSS PERFORMANCE CHARACTERISTICS

BANDS 4, 5, 6, and 7

SPECTRAL BANDS

4	.5 - 6 µm
5	.6 - .7 µm
6	.7 - .8 µm
7	.8 - 1.1 µm

Instantaneous Field of View (IFOU)	86 x 86 m radians
Number and type of detectors	
Band 4, 5, and 6	6 photomultiplier tubes
Band 7	6 Silicon photodiodes
Information Bandwidth	42.3 KHz per detector
Sampling Rate (each Detector)	100,418 sample per second
Quantization	6 Bits
Samples per line	3317
Nominal Aperture Diameter	22.8 cm (9 inches)
f/no	3.6
Ground Resolution Element	78 meters (260 feet)
Swath Width	185 km (100 nm)
MTF, minimum	0.29 for 0.075 mr sinusoidal bars
Inflight calibration	(a) Internal lamp sources (b) Sun
Gain steps	- Commanded to step between x1 and x3 (in Bands 4 and 5 only) - linear mode or compressed mode (Bands 4, 5, and 6 only)

Attachment A

MSS PERFORMANCE CHARACTERISTICS

(Band 8)

Spectral Band	10.4 to 12.6 um
Dynamic Range (Scene Apparent Temperature)	$260^{\circ}K$ to $340^{\circ}K$
Instantaneous Field-of-View	0.26 x 0.26 m radians
Number of Detectors	2
Information Bandwidth	14.1KHz
Effective Aperture	308 cm^2
f/no	1.9
Ground Resolution Element	238 meters (780 feet)
Lines/Scan	2
Swathwidth	185 km (100 nm)
Detector Material	Hg Cd Te (Mercury-Cadmium Telluride)
NEP (Noise Equivalent Power)	2.5×10^{-10} watts
Responsivity	3100 V/Watt (nom)
Cooler FOV	$72^{\circ} \times 100^{\circ}$
Cooler	Passive Radiator
Detector Operation Tem.	$100 \pm 10^{\circ}K$
NEΔT (Noise Equivalent Temperature Difference)	$1.52^{\circ}K$ for $300^{\circ}K$ scene
MTF (Modulation Transfer Function) minimum	0.29 for 238 meter sinusoidal bars
In flight Calibration	a. Ambient black body. b. Reflected detector
Gain Steps	Commandable in eight (8) gain levels in increments of 1.22 (i.e., 1.0, 1.22, 1.22^2... 1.22^7)

Attachment A

LANDSAT-C RBV: FUNCTIONAL CONSTANTS SUMMARY

o Landsat-C Orbit Altitude	911.8 km (492 n.m.)
o Imaging Tube	2" RBV
o Delfection Focus	Electromagnetic
o Imaging Size on Target	25.4 mm x 25.4 mm
o Number of Cameras	2
o Ground Coverage/Camera	98 x 98 km
o Highlight Irradiance	2,013 - mw/cm^2 - sr
o Spectral Coverage	.505 - .750 micrometers
o Lens Effective Focal Length	236 mm
o Horizontal Limiting Resolution (CNTR)	4500 TV Lines (90 Lines Per mm)
o Edge Resolution	80 % of Center
o Read Horizontal Line Rate	1250 Lines Per Sec.
o Active Horizontal Lines	4125 Per Image
o Video Bandwidth	3.2 MHz
o Shading	± 15% within 25.4 mm DIA Circle ± 25% Elsewhere
o Residual Image	$\leq$1%
o Image Distortion	± 1%
o Aspect Ratio	1:1 at Set-up
o Skew	$\leq \pm$ 0.5°
o Size and Centering	$\leq \pm$ 2%
o Peak Signal/RMS Noise	33 dB
o Erase/Prepare/Expose/Read Out	Staggered for 2 Cameras

Attachment A

LANDSAT-C RBV: FUNCTIONAL CONSTANTS SUMMARY

(Continued)

o Two Camera Cycle Rate	12.5 Sec
o Erase Time	0.5 Sec
o Prepare Time	8.5 Sec
o Total Read Out Time Per Exposure	3.5 Sec
o Available (By Command) Exposure Time	2.4, 4, 5.6, 8, or 12 ms
o Nominal Exposure Time	5.6 ms

DCS PERFORMANCE CHARACTERISTICS

o Transmitter Power Output	5 watts
o Nominal Transmitter Frequency	401.9 MHz
o Maximum Number of Sensor Inputs	8
o Number of Quantization Levels Per Sensor	256 (8 bits)
o Total Sensor Data Capacity Per Platform	64 bits

Attachment B

SATELLITE SCHEDULE OPERATIONS

At the beginning of each day the activity plans for that day are generated by the Operations Control Center (OCC) for each orbit's operation, based on sensor coverage requirements, observatory and payload status, network availability and the current cloud-cover predictions. Tracking and orbit adjust requirements, when required, are integrated with the coverage planning. Scheduling is coordinated with the Network Operations Control Center and NASA ground station availability is determined for both routine contacts and orbit adjust maneuvers. After integration of all the requirements and support activities, a final activity plan is issued which is an integrated time ordered sequence of events defining the observatory and payload scheduling and ground system operations for each orbit.

The following nominal payload operations have been developed as guidelines. Modifications to this proposed plan will be determined by your inputs.

1. The MSS 5th band will be operated at night. An average 40 scenes/day will be acquired in this manner. Sixteen scenes per day will be acquired and played back from the on-board tape recorders.

2. All five bands of the MSS will be operated during daylight. 160 scenes per day will be acquired. 100 will be recorded and played back.

3. The RBV camera system will be required to obtain an average of 160 RBV scenes per day (the equivalent of 40 MSS scenes). 64 will be obtained in real time. 96 will be acquired by use of the tape recorders. The RBV can be operated simultaneously with the MSS.

4. The maximum time for continuous operation during one orbit is 35 minutes. This requirement allows operations of Landsat-C over the foreign real time ground stations that are expected to be operational in 1978. It is also expected that the average time "on" of the payload will be 15 minutes per orbit. By excludng ocean areas from coverage by real time stations, this orbital coverage can be reduced to 12.5 minutes per orbit.

5. The MSS 5th band can be operated at any time throughout the orbit. This includes night operation and operations at all solar elevation angles, whereas the first four bands are normally operated only when the solar elevation angle is greater than 10 .

6. The RBV will be used to acquire data over selected areas on a once per season basis. On a daily average, the RBV will operate at a rate which will yield 20% of the daylight coverage obtained by the MSS. The longest pass with RBV and MSS operating simultaneously is estimated to be 25 minutes.

These limitations are defined by the capability of the Image Processing Facility at the Goddard Space Flight Center to process a total of 200 MSS scenes per day, average, and available power from the satellite.

Attachment B

DESCRIPTION OF TYPES OF AVAILABLE DATA PRODUCTS

Standard Landsat-C user products will be available from the Landsat Data Distribution Center (EDC) Sioux Falls, South Dakota in the following formats:

Product Number	Description of Product
1	241 mm MSS Bands 4, 5, 6, 7, 8 B/W positive or negative, 1:1,000,000 scale, geometrically and radiometrically corrected film products.
2	B/W paper products, MSS, positive only, 1:1,000,000, 1:500,000, and 1:250,000 scales.
3	241 mm RBV, Subscene A, B, C, D B/W positive or negative, 1:500,000 scale, geometrically and radiometrically corrected film products.
4	B/W paper products, RBV, positive only, 1:500,000, 1:250,000, and 1:125,000 scales.
5	Color transparencies, MSS, positive only, 1:1,000,000 scale.
6	Color paper, MSS, positive only, 1:1,000,000 1:500,000 and 1:250,000 scales.
7	Computer Compatible Tape (CCT), 9 track, 800 or 1600 BPI, geometrically and radiometrically corrected.
8	High Density Tape (HDT), in unique HDT format, geometrically and radiometrically corrected, up to 50 scenes per tape.
9	16 mm microfilm, catalogs and accession aids

NOTE: (1) Custom processed non-standard products including Quick Look Data, other scales, unique scene enhancement, other tape formats, uncorrected data, etc., are planned to be available at increased cost.

(2) Landsat 1 and 2 historical data will continue to be available in current standard product formats.

CUBIC CONVOLUTION

Cubic Convolution is an interpolation method used for geometric correction of Landsat video data. Data values are collected at a particular spacing. Often, however, when these image data are registered to a particular map or grid, a one-for-one match doesn't occur and it becomes necessary to "fill in the blank spaces." When this occurs, it is necessary to take neighboring points and interpolate to get a best estimate for the missing values. Cubic Convolution is one of the best techniques for finding such values.

Other simpler but less accurate methods which can be used to accomplish this include Nearest Neighbor or Bi-linear Interpolation. Higher order methods than Cubic Convolution also may be used. They are more accurate but require the use of more points and hence more computer power. This makes their application less desirable.

Cubic Convolution has the effect of providing a smoother looking image. It does not, however, correct for striping since striping is a phenomenon resulting from nonuniform detector response rather than from the "stretching or bending" of images. Striping ordinarily is corrected by other means such as those used during the radiometric calibration of sensor data.

Attachment D

Attachment E

United States Department of the Interior

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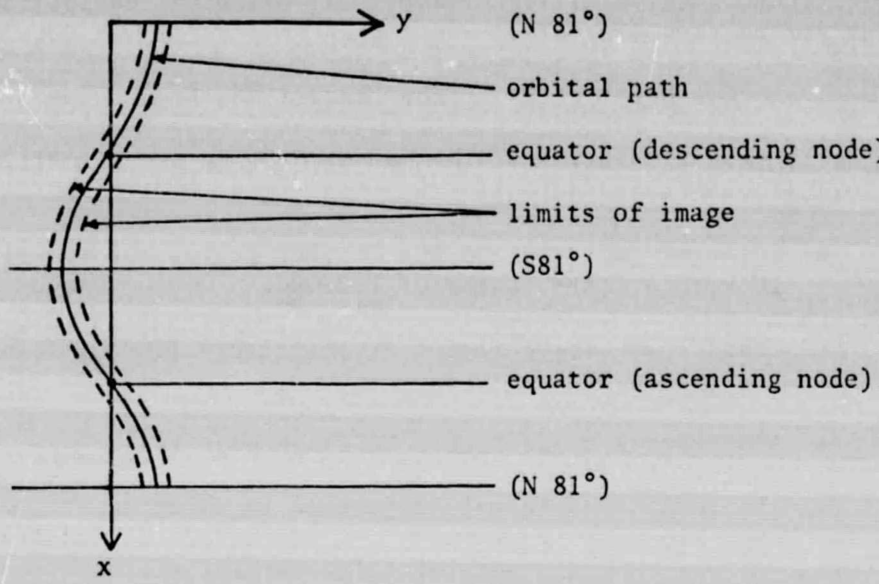
*By treating the projection plane as a cylinder (which is mathematically acceptable) the x values repeat themselves each orbit.

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-

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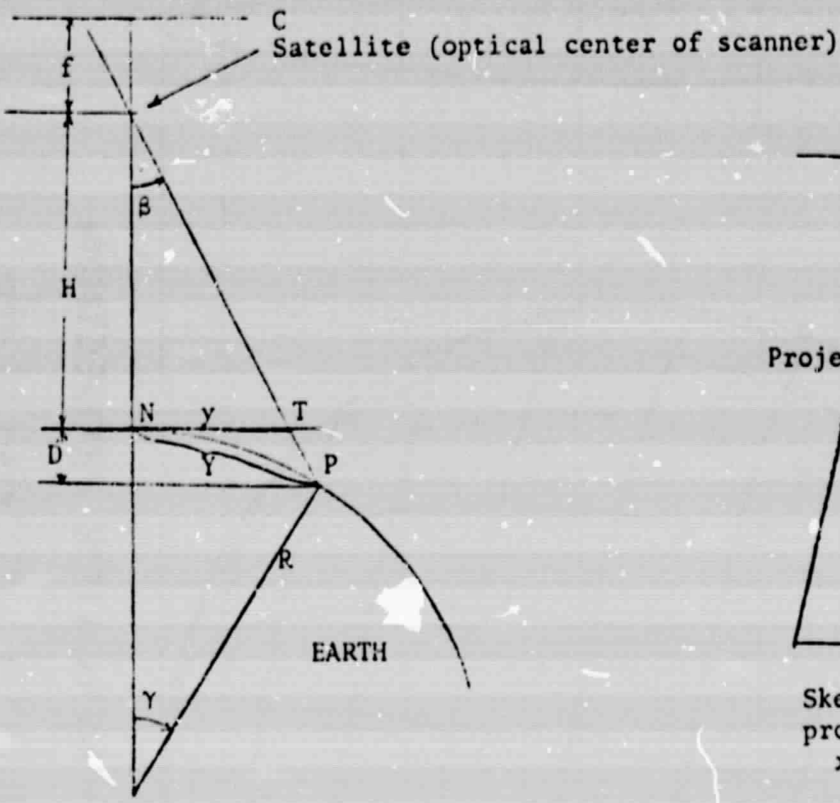
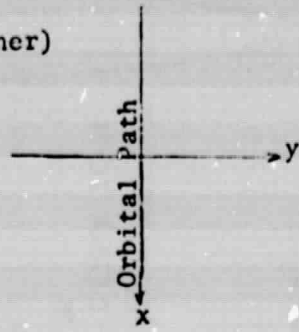
*All figures given are approximations. NASA is expected to make available exact figures which might be required for rigorous computations.

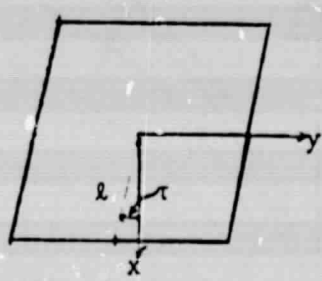
Attachment E

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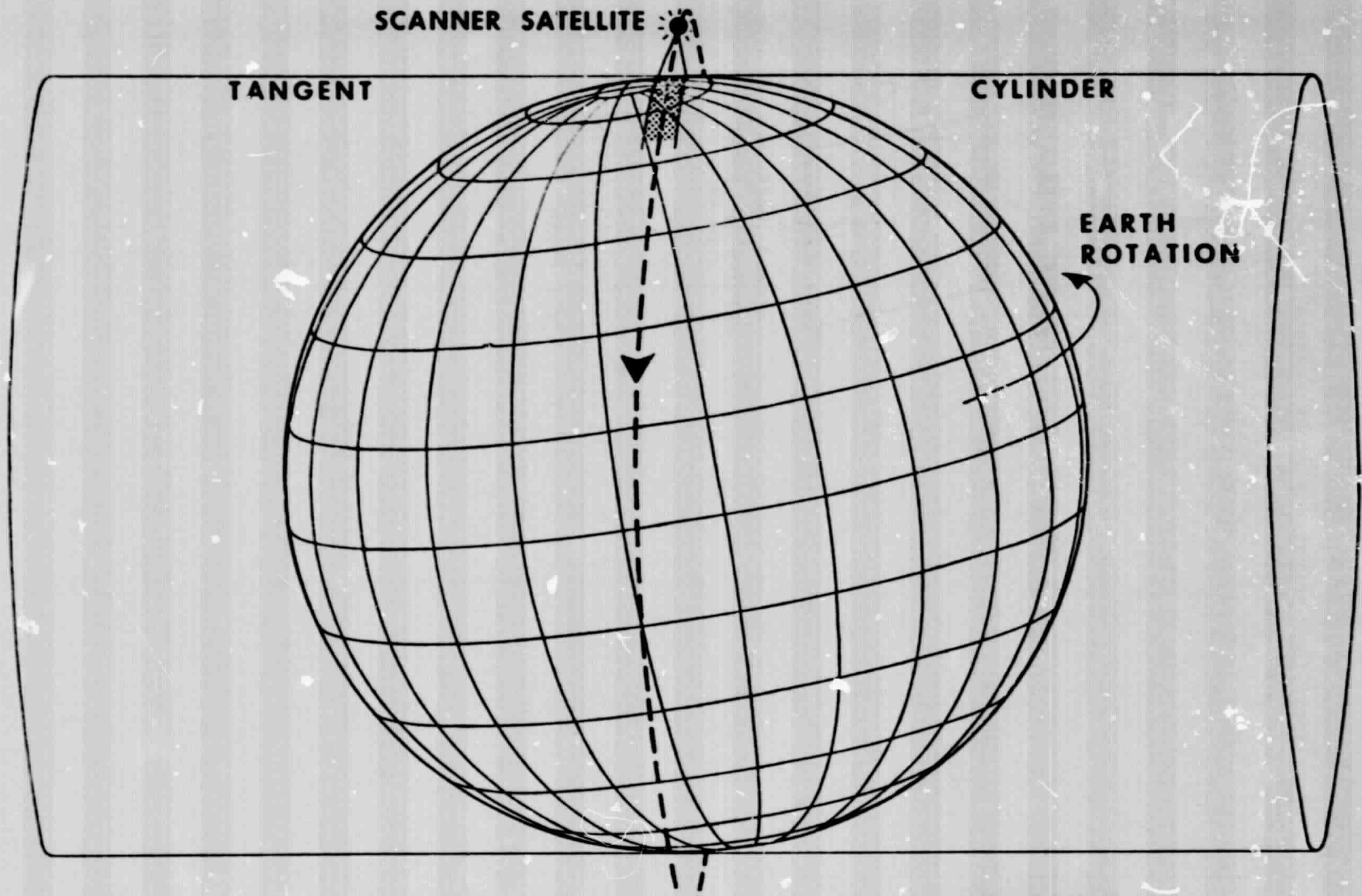
*If one disregards the small error introduced by earth rotation during the scan sweep (The maximum displacement in the x direction is only about 200 m for the 185 km scan length), the y direction on the actual image is that of the scan lines (as now configured). However the x direction of the projection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

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