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# ERTS-A Satellite Imagery

**External geometric effects on the imagery from an Earth Resources Technology Satellite will result from earth curvature, camera tilt, relief, map projection, etc.**

## INTRODUCTION

THE FIRST Earth Resources Technology Satellite (ERTS-A) is scheduled to be launched by NASA in 1972. With an expected lifetime of at least one year, this earth-sensing space system is designed to provide data for the Interior Department's EROS* Program and for similar programs of other agencies concerned with the survey of the Earth's resources.

ABSTRACT: *The first satellite designed to survey the Earth's resources is scheduled to be launched in 1972. This satellite, known as ERTS-A, will telemeter frames of imagery each covering 100-nautical-mile squares of the Earth. Except for the internal anomalies in the sensor system, the imagery, after being properly scaled, rectified, and controlled, may be considered an orthographic view of the Earth and used as a planimetric photomap. The accuracy of this photomap will be limited principally by the geometric fidelity of the sensor system rather than by external effects, such as relief displacement, which restrict the direct cartographic use of the conventional aerial photograph. ERST-A is not designed as a topographic mapping satellite but does have real potential for thematic mapping particularly in areas now covered by topographic maps.*

ERTS-A will produce telemetered imagery that must be spatially correlated to the Earth's surface. Existing telemetry satellites, such as ESSA and NIMBUS, provide orbital-position and sensor-attitude data from which this spatial relationship is derived. These data are relatively coarse but generally adequate for positioning and orienting the type of imagery involved. In the case of ERTS-A, position and attitude data are expected to control the imagery with respect to the Earth to about 10 km, although substantial improvement is expected in follow-on flights (ERTS-B, and so on). This accuracy may be adequate for many uses, but those who are concerned with precise positions and measurements desire accuracy approaching the resolution of the imagery, which is expected to be about 100 meters (m) at ground scale. The only foreseeable way of achieving such accuracy with ERTS-A is by controlling the imagery to identifiable points on the ground. If the imaging system were free of all internal anomalies, there still remain specific external geometric conditions which limit the accuracy of relating space imagery to the ground. This paper is concerned with these conditions and ways of minimizing their effects without resorting to point-by-point digital transformation of the imagery.

## GENERAL CONSIDERATIONS

Earth curvature, atmospheric refraction, camera obliquity, and terrain relief affect the geometry of the recorded imagery, and, if the imagery is used in map format, the fit to the map projection must be considered. Maps at 1:250,000-scale, cast on the Universal Transverse Mercator (UTM) projection, provide complete coverage of the United

* EROS (Earth Resources Observation Satellite) is a Department of the Interior program for the utilization of spacecraft and aircraft technology in resource surveying and management.

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States. Detail on them is considered comparable to that expected on ERTS-A imagery and, for purposes of this paper, this map series has been selected as the one to which the imagery will be compared. Thus five conditions external to the sensor system must be considered. The sensors now under consideration include return-beam vidicon (RBV) imagers and point scanners. The geometry of scanner imagery is relatively complex, whereas that of the RBV images is theoretically the same as that of a frame camera with equivalent optics. Thus this study concentrates on RBV imagery and assumes that the scanner imagery will be spatially correlated to that of the RBV.

All optical images, and particularly those resulting from a telemetered system, contain displacements (nonlinearities) resulting from the internal configuration and processing of the sensor system. The analysis of such displacements, which may be quite significant, are not covered herein. The improvement of the geometry of TV imagery is a separate problem which is currently the subject of considerable research effort. A geometrically perfect image, insofar as the sensor system itself is concerned, has been defined for this paper.

## Assumptions

Based on May 1969 data provided by NASA's Goddard Space Flight Center (GSFC), the following specifications for ERTS-A are assumed:

*Orbit*—Circular and sun-synchronous at 920-km (496 n mi) altitude.
*Inclination*—99° (9° W of N at ascending node). Daylight photography of U.S. is on descending limb (9° W of S at descending node).
*Verticality*—Sensor is held to within 1° of vertical (±0.7° on each axis). Attitude determination is to 0.14° (±0.1° on each axis).
*Image coverage*—16.22° across diagonal of square image. This angle gives ground coverage of 185 km (115 stat mi or 100 n mi) on a side.
*Optics*—Present specifications indicate 25.4-mm raster and 126-mm focal length, giving scale on raster of 1:7,300,000 at 920 km.
*Skew*—±0.7°.
*Ground resolution*—NASA has estimated the ground resolution of the point scanner to be something less than 61 m (200 ft), but the RBV, because it is a TV system, requires some detailed resolution analysis. An accepted method[1] for converting TV lines to optical line pairs is to divide the number of TV lines by $2\times\sqrt{2}$ for maximum scene contrast in the visible spectrum. For other than maximum contrast, the effective number of TV lines must be estimated and this number divided by 2 to obtain the conventional line-pair equivalence. Table 1 summarizes the expected resolution in the three RBV cameras.

## Specific Error* Analysis

The five external conditions that affect the geometry of the space imagery are treated separately in the following paragraphs and then summarized. Simplified drawings illustrating the resulting displacements are shown in Figure 1. The mathematical bases for the displacement values are covered in the references. As the system has not been rigidly defined and several variables will always exist, only two significant figures are shown for computations.

### Earth Curvature

A space photograph is a perspective-plane projection of the curved surface of the Earth, and therefore its imagery is distorted. The mathematical relationship between such a projection and the reference surfaces of the Earth (sphere and ellipsoid) has been developed and should be used where precise transformations are involved. A space image can theoretically be spatially transformed to any map projection desired, but no plane projection can depict the Earth's surface in its true form. However, displacements resulting from earth curvature can be minimized by various means.

For purposes of this report, radial displacements due to earth curvature have been calculated in relation to the image nadir. This method gives a simplified relationship of the photoimage to the Earth's surface. This relationship is widely used in photogrammetry and aerotriangulation in correcting for earth curvature. If the photoimage is spatially corrected to remove such radial displacements, it is mathematically transformed from the original perspective projection to the azimuthal equidistant projection. Transforming imagery to this projection may or may not be worth the effort involved. In the case of ERTS-A, it is not recommended at this time.

In ERTS-A the earth-curvature effect is one of the most significant of the external effects on the geometry of the imagery. The displacement of a point in the corner of the imagery can amount to 200 m assuming that the imagery is controlled to points near the nadir. The 200 m represents the difference between the distance from the corner point to the nadir as scaled on the photo and the equivalent distance on the ground. Figure 2 indicates the displacements under two conditions of scaling. As indicated, the maximum posi-

* The term *error* is used to denote image displacements resulting from various geometric and mathematical conditions.

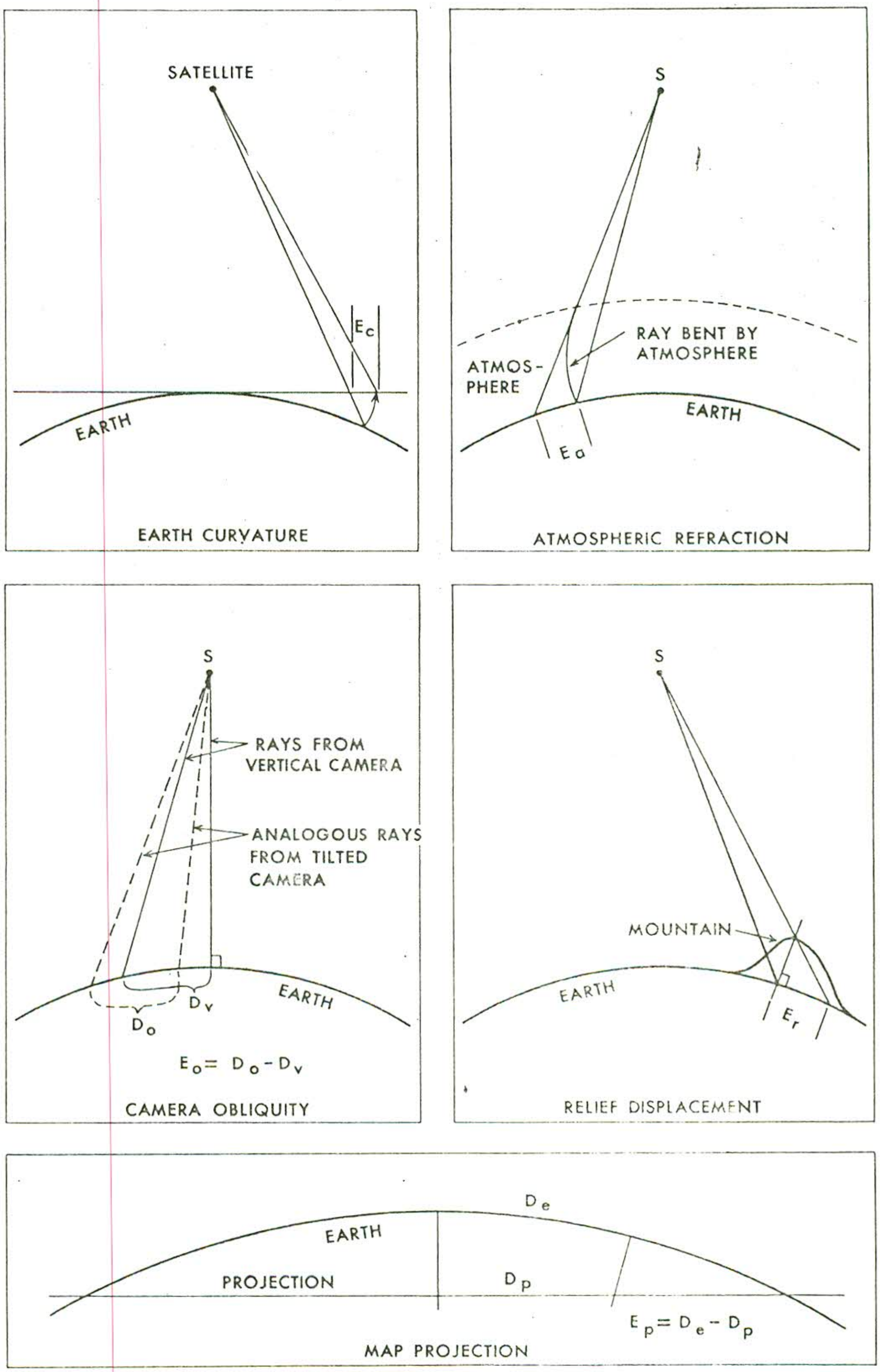


FIG. 1. Simplified drawings illustrating displacements (errors) in satellite imagery.

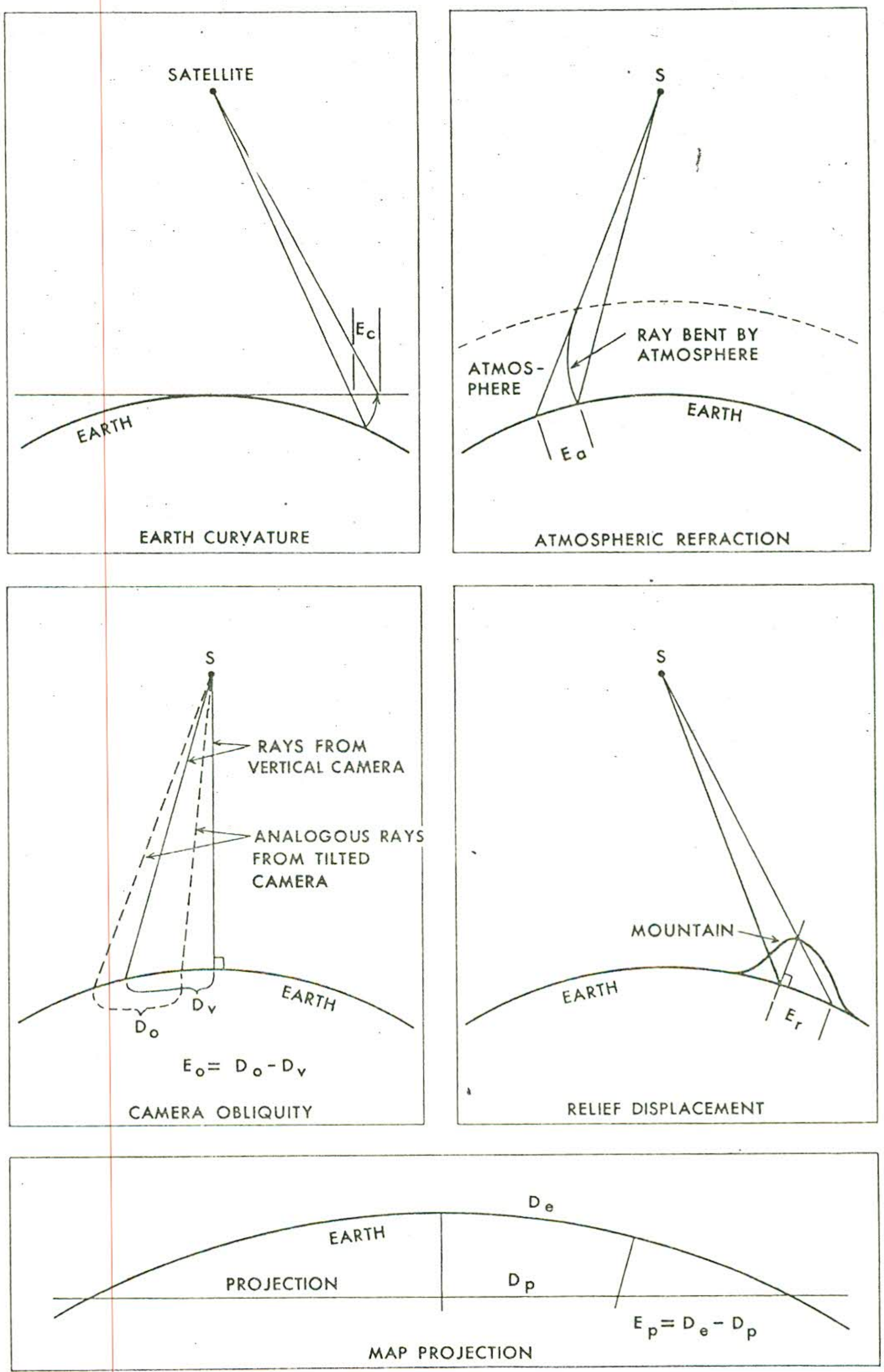


FIG. 1. Simplified drawings illustrating displacements (errors) in satellite imagery.

TABLE 1. EXPECTED GROUND RESOLUTION OF RBV CAMERAS BY SPECTRAL BANDS AND SCENE CONTRAST

| | *Camera #1* (*Green*) (*475–575 nm*) | *Camera #2* (*Red*) (*580–680 nm*) | *Camera #3* (*Infrared*) (*690–830 nm*) |
|---|---|---|---|
| Scan lines | 6,000** | 6,000** | 6,000** |
| Effective TV lines at *maximum* contrast | 4,240[1] | 4,240[1] | 3,400* |
| Equivalent optical resolution in terms of line pairs | 2,120 | 2,120 | 1,700 |
| Ground resolution at maximum contrast (meters)** | 87 | 87 | 109 |
| Effective TV lines at *10:1* contrast | 3,500* | 3,500* | 2,600* |
| Equivalent optical resolution in terms of line pairs | 1,750 | 1,750 | 1,300 |
| Ground resolution at 10:1 contrast (meters)** | 106 | 106 | 142 |

* Estimated by NASA (GSFC).

** NASA, as of January 70, indicates the number of scan lines will be reduced from 6,000 to 4,200. This means that all ground resolution figures given would be increased by 1.43.

tional error can be reduced from 200 m to 50 m by equalizing the maximum positive and negative displacements. For mosaicking purposes, this error may be further reduced by eliminating the image corners where the scale change is most rapid.

### ATMOSPHERIC REFRACTION

Based on papers by Schmid[2] and Schut[3] on refraction through the atmosphere, the maximum positional error of a point at the edge of the image that can be attributed to atmospheric refraction will be 0.34 m at ground scale and therefore negligible. This error is opposite in direction to the much larger Earth-curvature error with which it may be combined.

### CAMERA OBLIQUITY

ERTS-A attitude control will hold the camera to within 1° of vertical (±0.7° on each axis). In the worst instance (1°), a point in the corner of the photograph will be displaced with respect to the photo center by about 440 m, which may be additive to the curvature displacement. Auxiliary sensors are expected to indicate the actual satellite attitude to within 0.1° in each axis or 0.14° in the worst case. If such data are made available, the imagery can be rectified within such limits. The effect of the unknown tilt (0.14° max.) coupled with the residual Earth-curvature effect may, after rectification, leave a maximum positional displacement of about 53 m in an area which would have been covered if the sensor was truly vertical. In areas of identifiable control, the tilt errors can be combined with those of other causes and generally eliminated by an analytically derived transformation of the imagery. Such procedure is time consuming and is not recommended (except for special purposes) as long as attitude can be determined to the above specifications.

### TERRAIN RELIEF

The worst relief condition would occur where the imagery is controlled (scaled) to points of high elevation but a corner image is at much lower elevation, such as 1,000 m below the control points. In this instance the relief displacement of the corner point would be about 160 m and in the same direction as Earth curvature. In very rare occasions the displacement could be even larger, but by appropriate selection of control, it can normally be kept to a much smaller amount.

### MAP PROJECTION ERROR

In practice, positions and distances are usually measured on maps all of which have certain scale errors due to their particular projection. On large-scale USGS maps of the U.S. (1:63,360 and larger), this scale error (due to projection) is no more than 1:10,000 and can be disregarded. The 1:250,000-scale series is based on the Universal Transverse Mercator (UTM) projection, which involves scale error of as much as 1:2,500 at the center and edges of zones in the U.S. In this case the maximum positional error may be bout 42 m. It may be additive to the Earth-curvature error if one compares a distance on the map with one on the image.

### Error Summary

The five external errors considered are summarized in Table 2. Although a possible displacement of over 300 m is indicated by the table, such an error is highly unlikely. It could only occur if the four major conditions combine to produce an additive effect at a specific corner of the imagery. Three of these conditions produce errors in random directions, and, except for relief, the errors are functions of the squares of the distance from the nadir or center of the photo. Statistically they will combine to produce probable and standard errors throughout the imagery of less than 50 m or 0.05 mm at 1:1,000,000-scale.

### Significance

This report in no way indicates that there will not be significant geometric error in ERTS-A imagery. The telemetered image that does not contain such errors is yet to be obtained. However, investigations have indicated that the geometric fidelity of TV and optical scanner imagery can be improved. This report does indicate that image displacements caused by earth curvature, atmospheric refraction, camera obliquity, and terrain relief as well as scale errors due to map projection can, except in unusual circumstances, be disregarded by the user. This assumes that the imagery is obtained under specified conditions and is rectified and scaled as recommended. From a practical

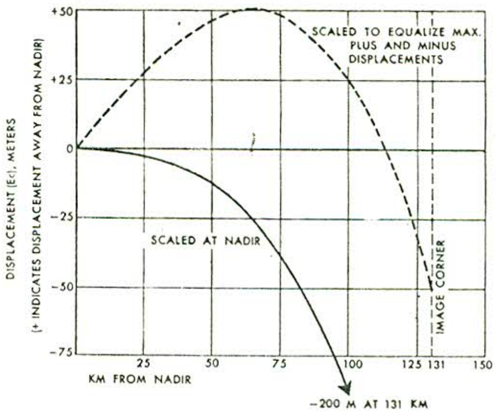


Fig. 2. Radial displacement on a vertical photograph due to earth curvature.

Table 2. Summary of Maximum Possible Displacements (Errors) in ERTS-A Imagery Due to External Conditions

| *Condition* | *Symbol (See Fig. 1)* | *Maximum Possible Uncorrected Displacement (meters)* | *Maximum Possible Displacement* After Proper Scaling and Rectification to ±0.14°* | | *Nature of Final Displacements* |
|---|---|---|---|---|---|
| | | | *At Ground Scale (meters)* | *At 1:1,000,000-scale* on 7.3″×7.3″ Format (millimeters)* | |
| Earth curvature | Ec | 200 } | 50 | 0.05 | determinable |
| Atmospheric refraction | $E_a$ | 0.34 } | | | |
| Obliquity of 1° | $E_o$ | 440 | 53 | 0.05 | not determinable |
| Terrain relief (for point 1,000 meters above or below control | $E_r$ | 160 | 160 | 0.16 | determinable in well mapped areas |
| Map projection (UTM in U.S.) | $E_p$ | *42* | *42* | *0.04* | determinable but of insignificant size. |
| Apparent combined error | | 840** | 300** | 0.30 mm** | highly improbable. |

* At 1:1,000,000-scale, maximum resolution involves about 10 optical line pairs per mm. This resolution is about equal to that of the capability of the human eye.

** Plus interaction (correlation) effects which could be considerable in unique instances.

standpoint, the individual images of ERTS-A can then be treated as orthographic views of a plane surface even though 115-statute-mile squares of the Earth's surface are involved. In effect, the imagery will then be an accurate map, subject only to the internal distortions and resolution limitations of the imaging system.

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