ERTS-1 SYSTEM PERFORMANCE OVERVIEW

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ABSTRACT

The ERTS-1 Spacecraft had a life of one year as a design goal. At the end of one year, the spacecraft was still providing about 130 scenes per day in multispectral images having resolution and radiometric accuracy better than prelaunch predictions.

INTRODUCTION

The mission of the ERTS-1 spacecraft and its supporting systems was to demonstrate the feasibility of multispectral remote sensing from space for use in practical earth resources management applications. Most of the papers presented during the symposium deal with the utility of the data for use in various scientific disciplines and practical applications. This paper provides the background of spacecraft and system performance which results in the data which the investigators have used.

THE ERTS SPACECRAFT

The ERTS spacecraft weighs about 950 Kg and is earth oriented, aligned to the local vertical within 0.7 degrees. The solar arrays provide about 500 watts when illuminated for the operation of the spacecraft subsystems and the payload which consists of the Multispectral Scanner (MSS), the Return Beam Vidicon Camera (RBV), two Wide-Band Video Tape Recorders (WBVTR), and a Data Collection System (DCS). The imaging instruments (RBV and MSS) provide multispectral images of the earth approximately 185 Km by 185 Km whenever turned on.

The orbit of ERTS-1 is sun synchronous with an inclination of 99.1 degrees crossing the equator in a North-South direction at about 0942 local time. Successive orbits are separated by about 2870 Km at the equator. On the following earth-day, the orbit will have moved approximately 159 Km to the west. This orbit results in repeating the same ground track every 18 days. In order to maintain the ground track within ± 18 Km, the spacecraft includes an orbit-adjust propulsion system.

SPACECRAFT PERFORMANCE

The primary objective of the ERTS-1 observatory was "the acquisition of synoptic, multispectral repetitive images from a satellite for a period of three months from which useful data can be obtained for investigations in such disciplines as: agriculture, geology, geography, hydrology, ecology, and oceanography." The design life for the spacecraft was one year (minimum).

Since its launching, the spacecraft has experienced two unexpected malfunctions and one anticipated degradation. During orbit 148 (August 3, 1972), a noise transient was experienced when WBVTR No. 2 was turned on. Analysis indicates that the problem was caused by internal shorting of the tape recorder power supply. Since that time, only WBVTR No. 1 has been used. During orbit 196 (August 6, 1972), a power transient was experienced when the RBV was turned on. In this case, analysis indicates a failure of a relay in the Power Switching Module of the spacecraft leaving the relay in a permanently "on" state. RBV turn-off (and "on") can still be accomplished by using a set of relays which control individual RBV functions. However, because of the difficult command sequence and the excellent performance of the MSS, the RBV has not been reactivated. Some 1,400 RBV scenes are available for analysis of the instrument's performance. A degradation in the performance of WBVTR No. 1 occurred during orbit 3462 (March 29, 1973) after the recorder design-life had already been exceeded. This has resulted in reducing the capacity of the recorder from its original thirty (30) minutes to approximately twelve (12) minutes. This capacity is still sufficient to record approximately one hundred scenes per day when out of contact with the receiving sites at Greenbelt, Maryland; Goldstone, California; and Fairbanks, Alaska.

Despite the anomalies experienced, the spacecraft and its payload are judged to have far exceeded their success criteria and design goals. After sixteen months in orbit, world-wide coverage was still being obtained at the rate of 130 scenes per day.

THE MULTISPECTRAL SCANNER

Because the vast majority of the data on which subsequent papers will be based are the result of observations by the MSS, a more detailed description of this instrument will be given.

The Multispectral Scanner Subsystem (MSS), gathers data by imaging the surface of the earth in four spectral bands simultaneously through the same optical system.

For ERTS-1, the four spectral bands are:*

- Band 4 0.5 to 0.6 micrometers
- Band 5 0.6 to 0.7 micrometers
- Band 6 0.7 to 0.8 micrometers
- Band 7 0.8 to 1.1 micrometers

Bands 4 through 6 use photomultiplier tubes as detectors; Band 7 uses silicon photodiodes.

The MSS scans cross-track swaths of 185 kilometers (100 nm) width, imaging six scan lines across in each of the spectral bands simultaneously. The object plane is scanned by means of an oscillating flat mirror between the scene and the telescope. The 11.56 degree cross-track field of view is scanned as the mirror oscillates $\pm$ 2.89 degrees about its nominal position. The MSS system is illustrated schematically in Figures 1 and 2.

*The number sequence for MSS bands corresponds to the image annotation convention used by the data processing facility.

The along-track scan is produced by the orbital motion of the spacecraft. The nominal orbital velocity causes an along-track motion of the subsatellite point of 6.47 km/sec neglecting spacecraft perturbation and earth rotation effects.

The line scanned by the first detector in one cycle of the active mirror scan lies adjacent to the line scanned by the sixth detector of the previous mirror scan.

The instantaneous field of view of each detector subtends an earth-area square of 79 meters on a side from the nominal orbital altitude. Field stops are formed for each line imaged during a scan, and for each spectral band, by the square input end of an optical fiber. Six of these fibers in each of four bands are arranged in a 4 by 6 matrix in the focused area of the telescope.

Light impinging on each glass fiber is conducted to an individual detector through an optical filter. An image of a line across the swath is swept across the fiber each time the mirror scans, causing a video signal to be produced at the scanner electronics output for each of 24 channels. These signals are then sampled, digitized and formatted into a serial digital data stream by a multiplexer. The sampling interval is 9.95 sec, corresponding to a cross track motion of the instantaneous field of view of 56 meters.

Due to the fiber optics physical separation and the detector time sampling, the spacing between fibers is set for different spectral bands to permit the radiometric levels to be compared without interpolating data. For a given selected spacing, this time interval between commutator samples in adjacent bands is made to coincide with the time interval between instantaneous fields of view. The commutator will then sample exactly the same point on the ground in each band.

During the retrace when the scan mirror makes the transit from east to west, a shutter wheel closes off the optical fiber view to the earth and a light source is projected onto the fibers through a variable neutral density filter on the shutter wheel. This process introduces a calibration wedge into the video data stream during this retrace interval. The calibration lamp makes it possible to obtain a check of the relative radiometric levels and also to equalize gain changes which may occur in the six detectors of a spectral band.

To produce "map like" images from data as obtained by the MSS, corrections must be made for the following factors:

- Non-linearity of mirror velocity
- Earth Rotation
- Attitude Rates
- Altitude Variation

These corrections (and others) are made in the NASA Data Processing Facility (NDPF) by merging spacecraft telemetry, emphemeris data, MSS calibration data, and the MSS video signal.

SYSTEM PERFORMANCE

The ERTS "product" which is employed by the majority of users is a photographic image. In addition to imagery, Computer Compatible Tapes (CCT's) are also available. The properties of images and CCT's which result from the serial action of the ERTS system (MSS, spacecraft, data acquisition, image generation, and photographic processing) are discussed below.

An attempt has been made through orbit adjustment (cross-track) and accurate timing (along-track) to hold the center of each image of the same ground region within as small an area as possible. Prelaunch predictions indicated a circle of 64 Km diameter could be achieved. Three orbit adjustments have been made to date. Figure 3 gives the cross-track drift which has been experienced since launch on July 23, 1972. Overall image framing in the March to October 1973 time period has held the center point within a 22 Km diameter circle two-thirds of the time.

The annotation of each ERTS image includes latitude and longitude tick marks. The position of these marks is computed from ephemeris data which gives the spacecraft position and spacecraft telemetry which gives the pointing direction. Prelaunch predictions estimated the annotation accuracy at about 800 meters. After some initial difficulties as reported at the last symposium, annotation accuracy was within 1000 meters during early 1973. After that time, the error became greater but is now becoming smaller again as shown in Figure 4. This variation may be a seasonal effect caused by the manner in which the spacecraft attitude measurement data are interpreted in computing spacecraft pointing direction.

Band to band spectral registration for the MSS has been measured as being better than 50 meters RMS. This is three times better than prelaunch predictions.

Temporal registration, i.e., from a scene taken at one time in a given band to a scene taken at another time in the same band, has also been significantly better than predicted. After fitting two images by translation and rotation, the RMS error is about 150 meters versus a prelaunch prediction of about 275 meters.

The usefulness of the ERTS images as a map depends not only on the quality of the images but also on the map projection to which they are being compared. It is not possible to make an indefinitely large mosaic of ERTS images because it is not possible to make a flat map of the curved surface of the earth while preserving the scale in two orthogonal directions. Within a given MSS image, the use of a single scale factor results in errors of less than 200 meters RMS in measuring the location of one feature relative to another.

The ability to see small features in an image is limited by the instantaneous field of view (IFOV) among other factors. As discussed above, the IFOV is 79 meters square. This numerical value is in fact the measured resolution for relatively good contrast linear targets such as piers in a harbor. For long, high-contrast targets, such as concrete bridges over water, structures as narrow as 40 meters can be observed. Investigators report routine observation of ponds 7 acres and larger in size. Such a pond would be about 180 meters in diameter.

Radiometric accuracy of the system depends on optical performance of the instrument, stability of the calibration lamp, lack of noise in the electrical transformations and transmissions, proper computer processing, and correct utilization of the radiometric transfer characteristics of the film recording medium. The radiometric stability of the MSS instrument and spacecraft system is evidenced by the fact that radiance measured over Death Valley on the same calendar date at a one year interval has varied less than two (2) percent. The radiance over this site during the year follows a cosine curve in phase with the sun angle as would be expected, Figure 5.

Many investigators have observed "banding" or "striping" in images. This is caused in part by the fact that a single image in a given spectral band is made by six individually calibrated detectors and also because the eye of the observer is more sensitive to changes in radiance than is the on-board calibration system. A change in the manner in which the calibration data is applied and a correction of an error have reduced banding after December 1972. On recently produced CCT's, radiometric noise while viewing a uniform scene is less than 5% of measured radiance.

The utility of film for radiometric measurements depends in part on the accuracy of the gray-scale calibration steps. Data for 264 images processed in October 1973 are presented in Figure 6. Here, nominal transmission of the gray-scale steps is shown together with the variation allowed by the original specification. Actual performance is shown as one-sigma bars for the thirty-one samples measured. It is well within specification.

EARTH COVERAGE

A history of the coverage obtained by ERTS-1 from the receiving sites during each 18 day coverage cycle is given in Figure 7; 20 cycles are accomplished in one year. As can be seen, there was a dip in the scenes acquired during the tape recorder difficulties in March 1973, and a somewhat lower overall level thereafter. However, recent experience shows that while the sun angle is low in the Northern Hemisphere, 50 scenes per day are currently being collected at U.S. receiving sites via real-time transmissions and 85 scenes per day via tape recorder.

The secondary objectives of the ERTS-1 mission were: (1) the acquisition of complete United States' coverage, largely cloud free, with either the Multispectral Scanner or the Return Beam Vidicon camera systems, or both; (2) the acquisition of coverage over the major land masses of the earth with either the Multispectral Scanner or the Return Beam Vidicon camera system, or both; and (3) demonstration of the relay of data from remote ground based platforms via the ERTS-1 satellite.

All of the United States has been covered at least once with less than 30% cloud cover. Some areas have been covered more than twenty times. World-wide coverage with less than 30% cloud cover during the first year of operation is illustrated in Figure 8. Recently, as the requirements of investigators have been reduced, the spacecraft has been operated to begin filling in the blank areas. It should be noted that this "map" is a projection in which ERTS orbits are vertical and latitudes are measured in terms of ERTS frames. Therefore, the land masses are distorted.

Over one hundred data collection platforms have been in use for the past eight months. The original requirement was that at least one data transmission be collected from each platform every twelve hours. Actual performance has provided an average of eight transmissions in every twelve hour period.

COOPERATIVE DATA ACQUISITION

In addition to the data acquired by U.S. Receiving stations, ERTS data are acquired by Canada at Prince Albert and by Brazil at Cuiaba. Total statistics for scenes acquired through November 1973 are approximately as follows:

United States	76,140
Canada	12,403
Brazil	4,527
Total Scenes	93,070

These data are available to any purchaser who may wish to use them for the better utilization of the earth's resources.

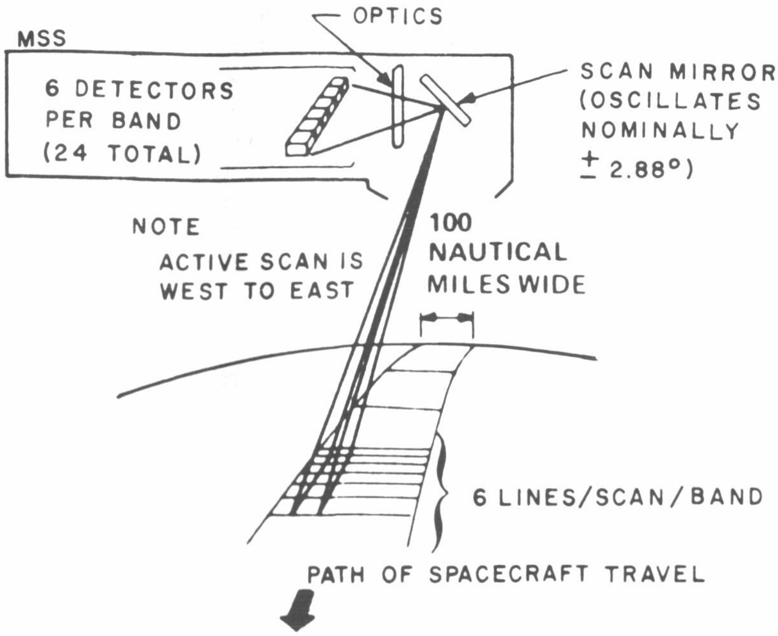


Figure 1.

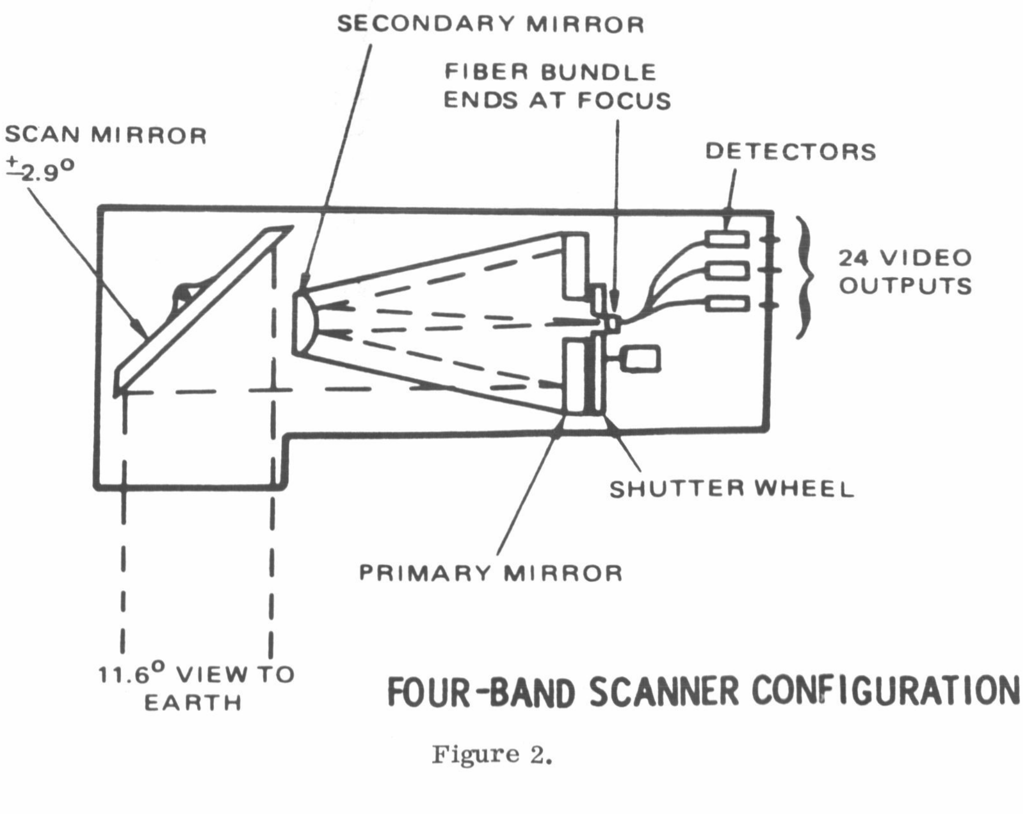
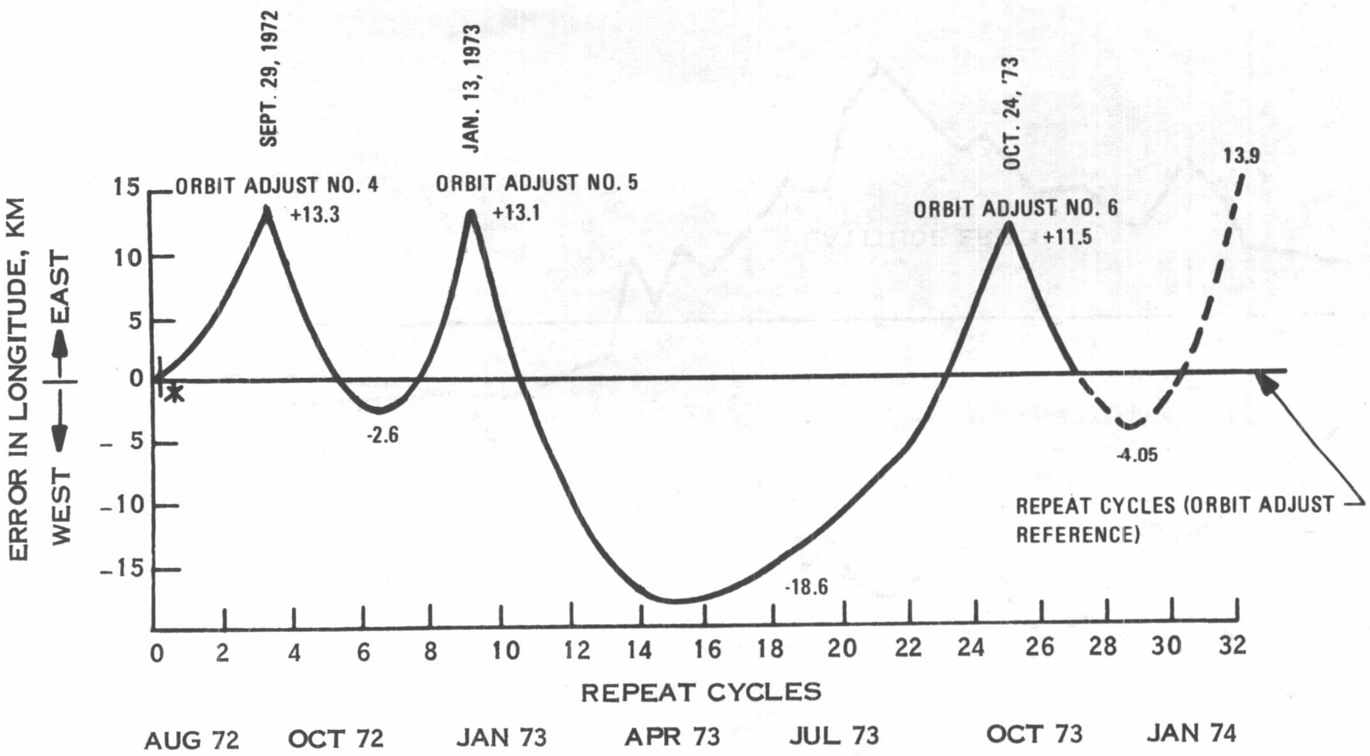


Figure 2.

CROSS TRACK DRIFT



*ORBIT ADJUST NO'S 1,2,3, TO ACHIEVE NOMINAL PARAMETERS

Figure 3.

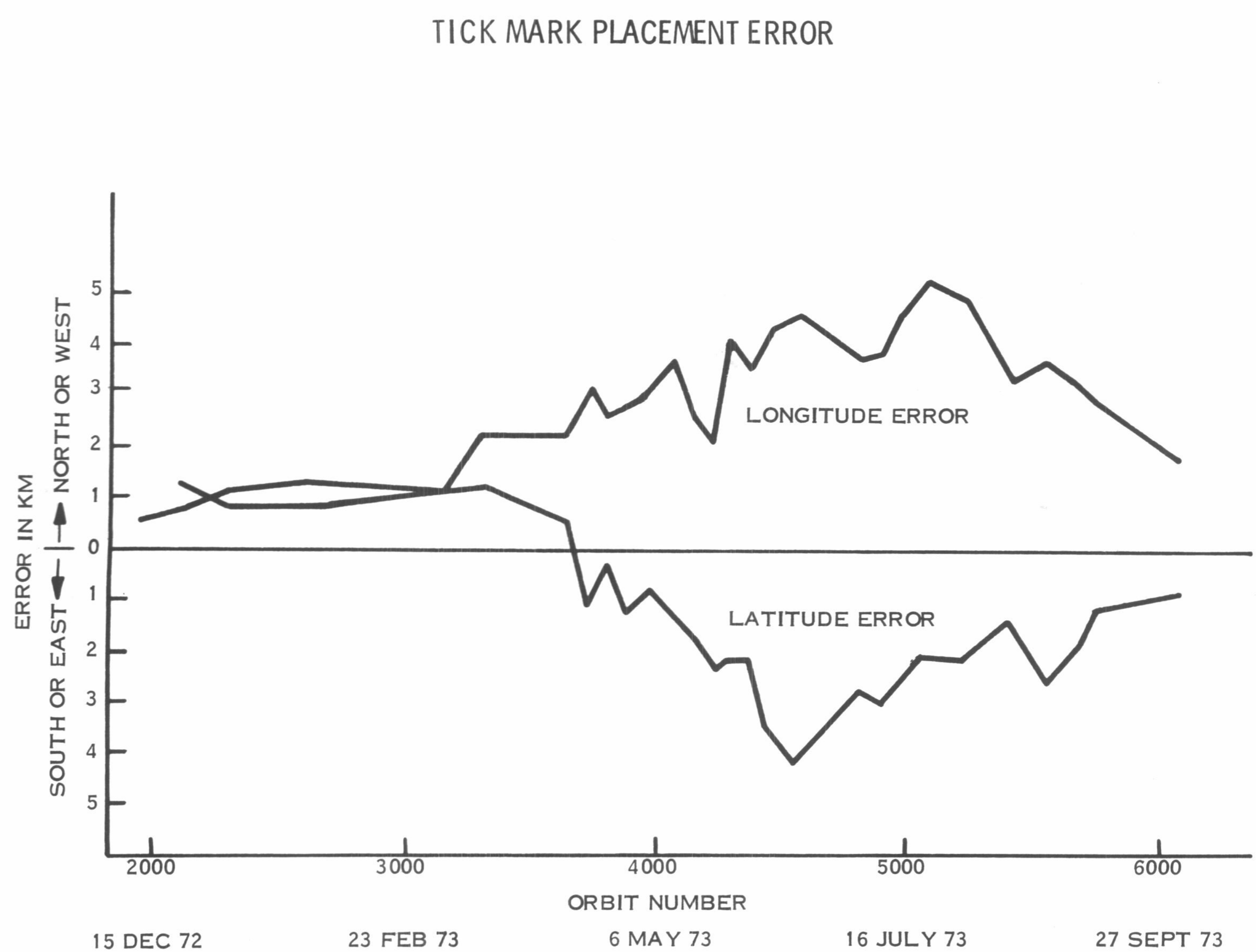

TICK MARK PLACEMENT ERROR
ERROR IN KM
SOUTH OR EAST
NORTH OR WEST
5
4
3
2
1
0
1
2
3
4
5
LONGITUDE ERROR
LATITUDE ERROR
2000
3000
4000
5000
6000
ORBIT NUMBER
15 DEC 72
23 FEB 73
6 MAY 73
16 JULY 73
27 SEPT 73

Figure 4.

AVERAGE RADIANCE MEASURED AT 11 DATES OVER 1 YEAR

RADIANCE EXTRAPOLATION

DATA		K COS Z		MSS BAND 7
9/9/73	38%	9/9/73	36%	15 MEASUREMENTS PER IMAGE
9/14/72	37%	9/14/72	35%	9.5 IN. 3RD GENERATION POSITIVE
Δ	1%	Δ	1%	DEATH VALLEY TEST SITE

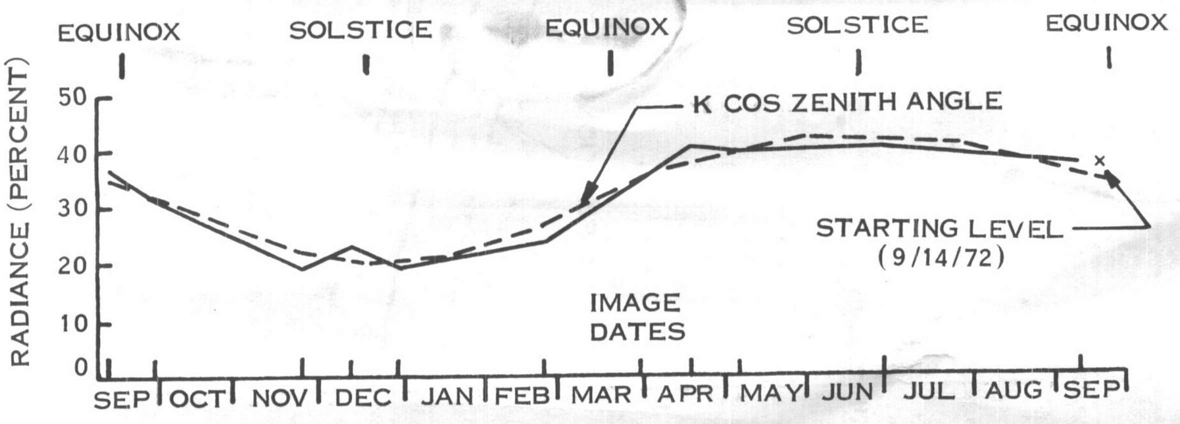


Figure 5.

3rd GENERATION 70 mm FILM
DENSITY VS GRAY SCALE

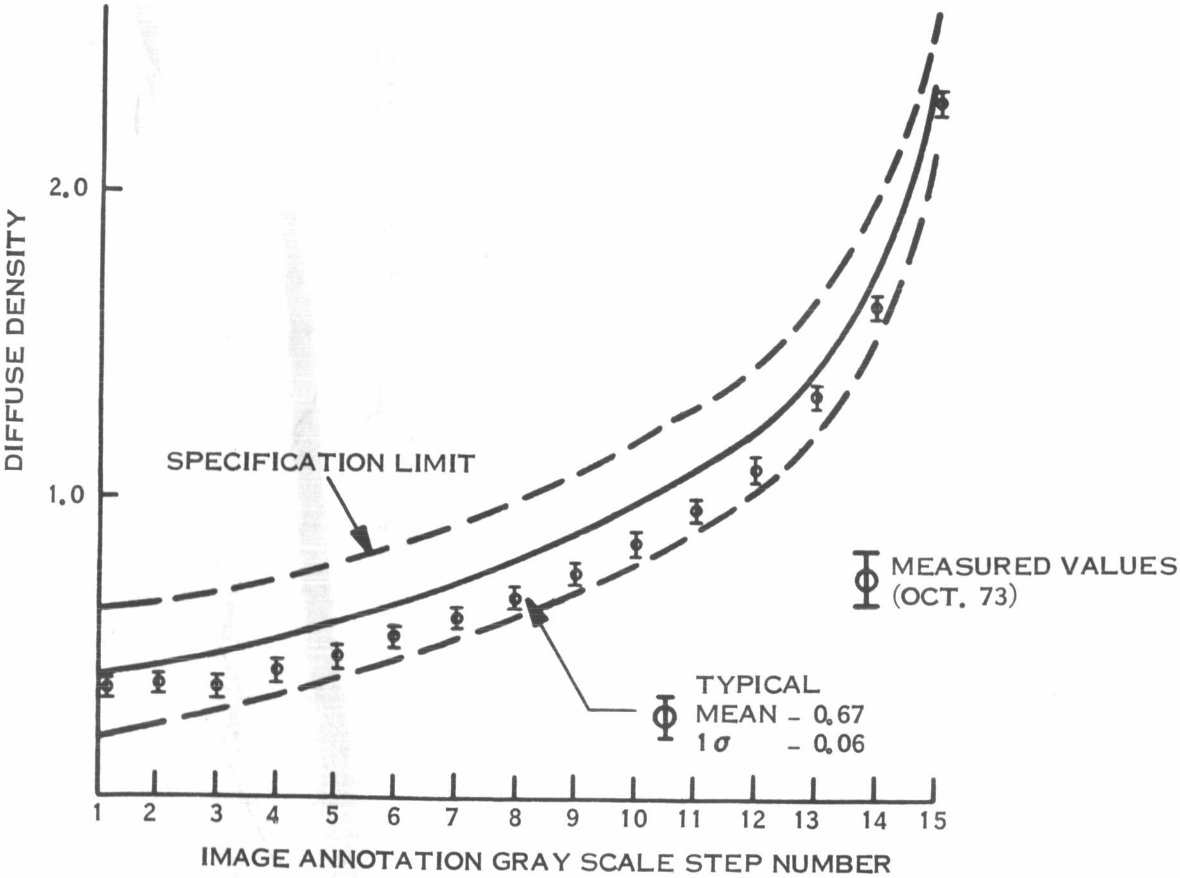


Figure 6.

ERTS SCENE ACQUISITION HISTORY BY CYCLE

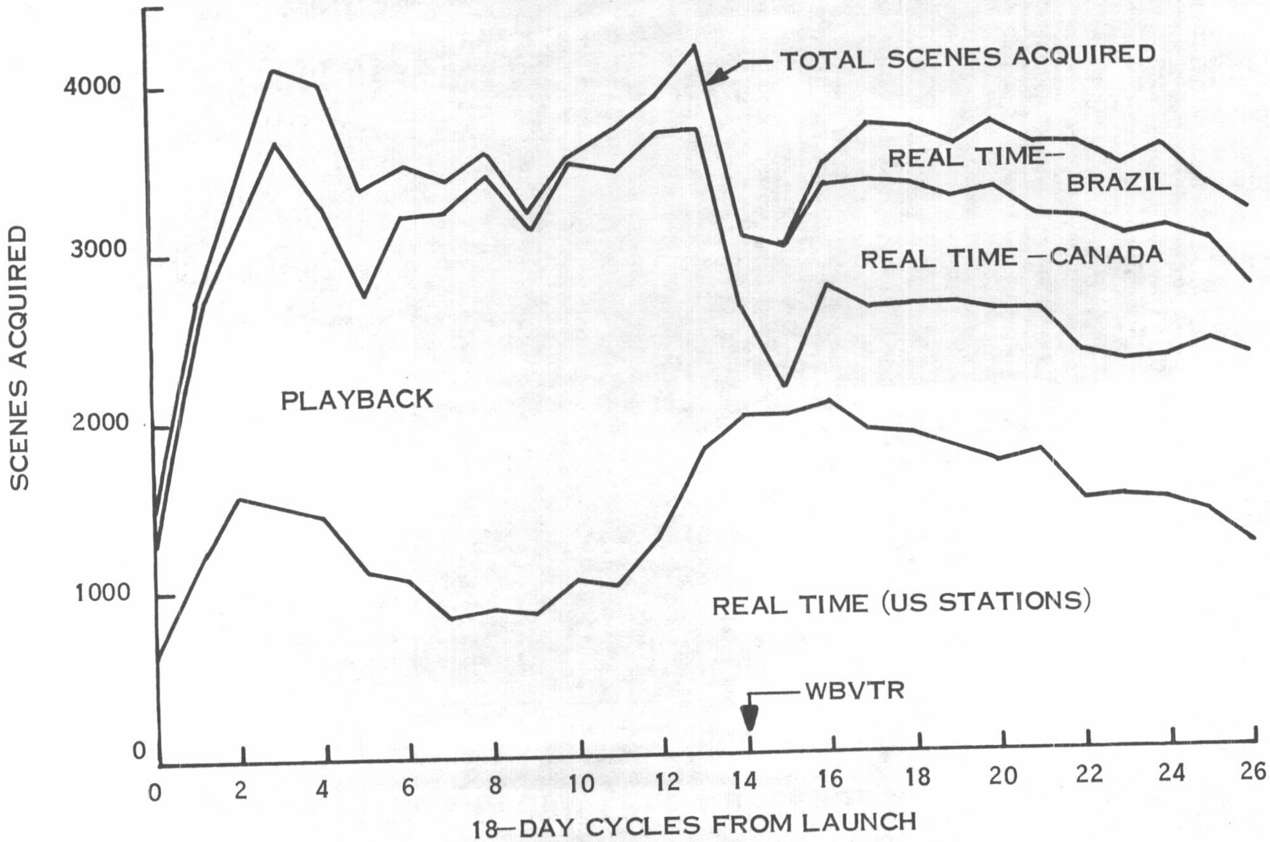


Figure 7.

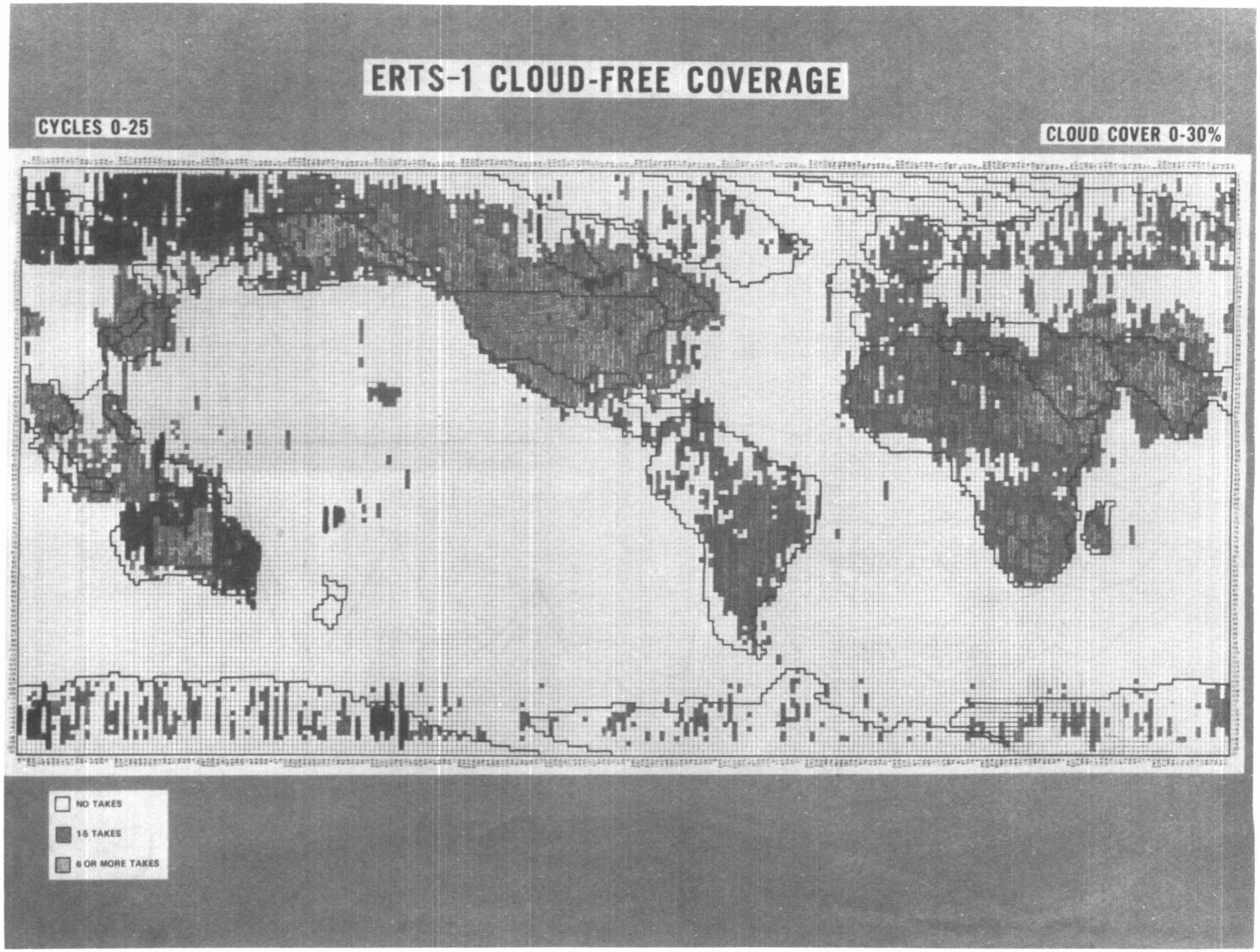

ERTS-1 CLOUD-FREE COVERAGE
CYCLES 0-25
CLOUD COVER 0-30%
NO TAKES
1-5 TAKES
6 OR MORE TAKES

Figure 8.