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ERTS-1 DATA PRODUCT PERFORMANCE

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ABSTRACT

The quality of the ERTS-1 data products produced during the initial months of system operation are evaluated. Quantitative performance data - principally geometric and radiometric accuracy and resolution - are determined for these data products. A comparison of these measurements with prelaunch predictions is also made.

INTRODUCTION

This paper is an assessment of the overall quality of the data products collected, produced and distributed by the ERTS-1 system during its initial period of sustained operation. This assessment is intended to quantify the inherent characteristics of the data products for investigators and experimenters involved in its scientific interpretation and analysis.

The period of evaluation covers the first three to six months of ERTS operation. Most of the data evaluated was collected during the first five eighteen day coverage cycles (the first three months) with more selectivity during the fourth through sixth months of operation. In order to keep the amount of data evaluated to a reasonable quantity while still maintaining a good sampling throughout the successive coverage cycles, test sites were selected which provided imagery suitable for making quantitative measurements (i.e. sufficient ground truth, urban detail, fairly constant atmosphere, large scale inert areas, etc.). System corrected imagery from each site in both 70 mm and 9.5 inch formats were ordered from the NDPF using the normal "standing order" procedure. This data was supplemented as required with system corrected imagery from other test sites.

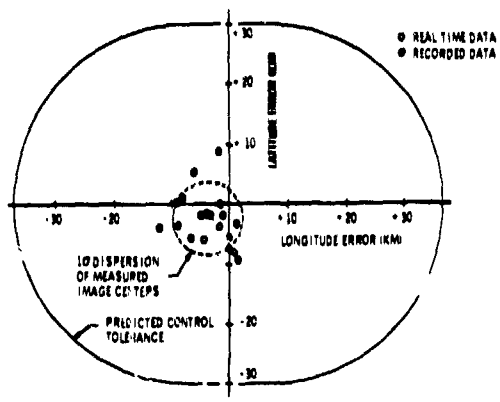
The data was analyzed to determine its quality in terms of geometric accuracy, resolution and radiometric accuracy. For reference these measured results were compared to the prelaunch estimates published in the ERTS Data Users Handbook. By repetitive analysis of data taken at different times performance indicative of sustained operation was possible and allowed short term or start up type anomalies to be differentiated from normal performance or legitimate trends.

GEOMETRIC ACCURACY

The geometric quality of system corrected photographic data was evaluated and measured over a broad set of parameters ranging from the degree of control over the geographic areas imaged by the ERTS sensors to the precision with which a picture element in one spectral image can be related to that in another.

Image Center Control. Initial program goals were established to control the spacecraft orbit and attitude, compute the ephemerides from tracking data, command the sensors and frame the imagery so that nearly the same geographical area on the earth would be contained in imagery collected on successive coverage cycles. Prelaunch tolerances on the control of image centers was predicted to be within 30 km in the in-track direction and 37 km in the cross-track direction of a predefined matrix of "nominal" image center locations. Figure 1 shows the difference between measured and the corresponding "nominal" image centers for test sites in the U.S. (real time) and abroad (recorded). Data Collected during a one month period following discontinued use of the RBV cameras on 6 August 1972 are excluded from the data set since during this period a new image framing technique had to be developed and unusually large errors were experienced. Thd dispersion of the data is quite small (> 6 km 1σ) with a slight offset from nominal to the south and west, due to spacecraft attitude. Since spacecraft attitude will vary principally with spacecraft position in orbit and sensor duty cycles, this bias will vary for test sites at different latitudes, but at a latitude, well within the overall tolerance limits. The latitude of the U.S. and most of the foreign test sites selected for this evaluation were apprc imately the same.

Figure 1
IMAGE CENTER CONTROL
(VARIATION FROM NOMINAL CENTER)



Absolute Location. Images are annotated with alphanumeric data and latitude and longitude tick marks to relate the image content to an earth reference. Absolute location is a measure of the accuracy with which the true latitude and longitude of points in an image can be determined using the tick marks at the edge of the image. Figure 2 shows the trends in location errors versus time. The large errors following launch are attributable to several "bugs" in the annotation software. After the correction of these, errors ranged in the one to three kilometer region as additional refinements in the annotation processing were instituted. Periodic measurements made during the early months of 1973 show these errors to range from 500 to 1100 meters, comparing reasonably well with prelaunch predictions of 800 meters.

Figure 2

LOCATION ACCURACY
(SYSTEM CORRECTED DATA)

2000 - 7000 METERS	LAUNCH THROUGH MID-OCTOBER
1000 - 3000 METERS	MID-OCTOBER THROUGH DECEMBER
500 - 1100 METERS	1973
~800 METERS	PREDICTED

Band-to-Band (Spectral) Registration. Band-to-band or spectral registration is the measure of how well points in an image from one spectral band overlay the corresponding points in another band from a single observation of a ground scene. Table 1 shows that registration errors are about three times smaller than prelaunch predictions, and, in the case of the MSS, approach the resolution limit of the sensor. This performance is attributable to better than expected stability at the sensors and ground processing equipment as well as accurate calibrational/correction data.

Table 1

BAND-TO-BAND (SPECTRAL) REGISTRATION (METERS, RMS)

	MEASURED	PREDICTED
MSS	60	159
RBV	110	336

Temporal Registration. Temporal registration is the measure of how well points in one spectral band overlay the corresponding points in that same spectral band from different observations of the same scene. The "best fit" is determined by translating and rotating one image with respect to the other so that the RMS value of the distance between corresponding pairs of points is minimized. MSS temporal registration errors are shown in Table 2. Again, the results indicate actual performance to be significantly better than predicted. Since repetitive RBV data was not available, no measurement could be made.

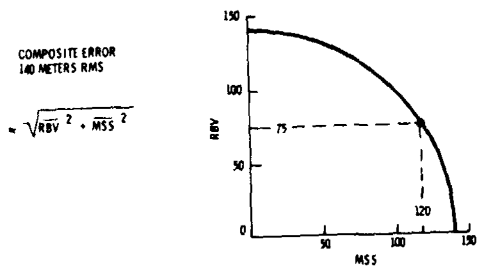
Table 2

TEMPORAL REGISTRATION (METERS, RMS)

	MEASURED	PREDICTED
MSS	185	~ 275
RBV	NOT MEASURED	~ 350

Relative Mapping Accuracy. Relative mapping accuracy is the measure of how well points in an image can be located with respect to other points in that image; that is, it is the measure of how well the internal distortions within an image are corrected. An excellent, and rather easy to obtain, indirect measure of the combined relative mapping accuracy of both MSS and RBV images can be made by comparing images of the same scene from both sensors. That is, by translating, rotating and scaling points in one band of an MSS image (usually the visible red) with the corresponding points in the RBV image, a measure of the combined errors of both images is made. This composite error is 140 meters. It is not possible, using this method, to separate the total into the contribution from the individual sensors. (See Figure 3) If we assume RBV and MSS relative mapping errors to be roughly equal, each would be just under 100 meters RMS. A distribution of RBV and MSS errors of 75 meters and 120 meters respectively is probably a more realistic estimate.

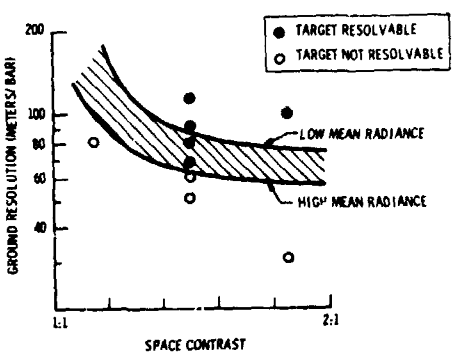
Figure 3
RELATIVE MAPPING ACCURACY



RESOLUTION

Image Resolution. The predicted resolution of ERTS products is based on analysis using standard tribar targets. Since proper targets of this type are not available in ERTS images, natural patterns of grossly equivalent form were used. These were identified and located using high resolution aircraft imagery. The ERTS images were then examined to determine whether these patterns could or could not be resolved. Pier structures in harbors proved particularly useful. Contrast was a subjective estimate. Figure 4 shows a comparison of this type measurement with predicted resolution curves for one band of the MSS. Plotted as solid circles are patterns that could be resolved. Open circles are patterns that could not be resolved. Agreement with predicted resolution is quite good. Similar results were obtained for other MSS bands and for RBV data.

Figure 4
PREDICTED VS MEASURED MSS RESOLUTION (BAND 2)



Resolution of Computer Compatible Tape (CCT) Data. The inherent resolution of system corrected CCT data is better than that of standard photographic image products since it is not degraded in any way by the image generation and photographic copying processes. A measure of CCT resolution, albeit subjective, can be made from examination of an enlargement of a portion of a scene from a CCT. For reference purposes Figure 5A is a high resolution aircraft image of a portion of the downtown Washington D.C. area. Figure 5B is an enlargement of a small portion (about one-four-hundredth) of a single ERTS frame. The enlargement was done digitally

Figure 5A High Resolution Aircraft Image

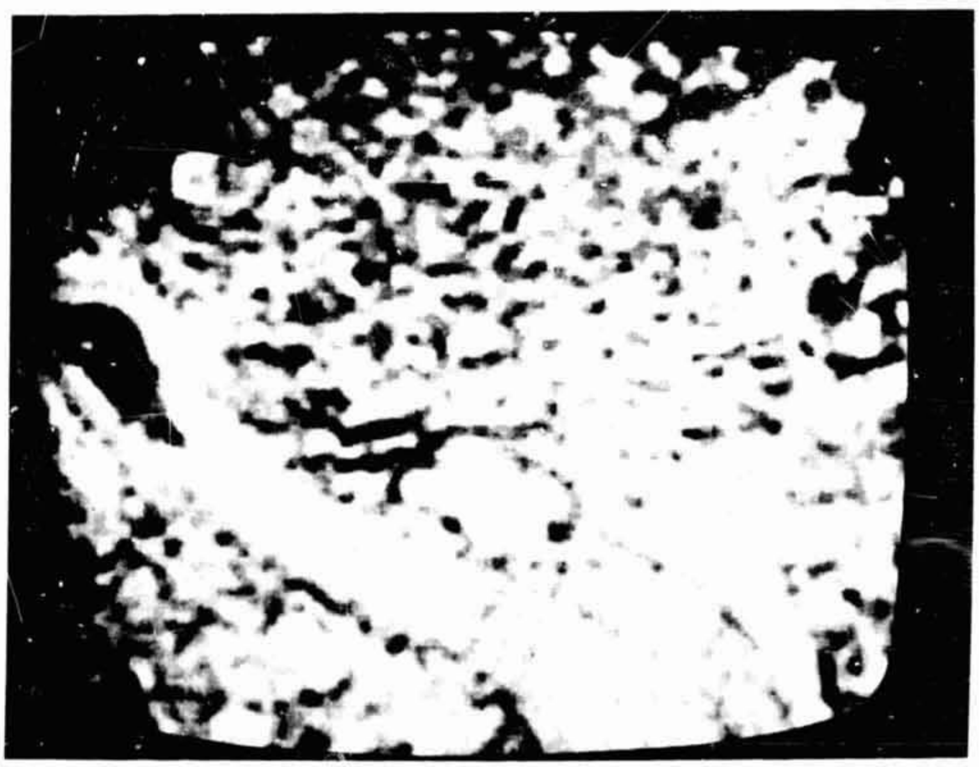


Figure 5B Enlarged Filtered CCT Image

and then filtered and displayed on a TY type monitor at a scale such that the resolution of the TV monitor does not substantially affect image quality. Features as small as the Jefferson, Lincoln and Roosevelt Memorials and Washington Monument are detectable.

RADIOMETRIC ACCURACY

Radiometric Transfer Function. The radiometric transfer function relates film transmission to sensor output and, therefore, also to input radiance. The nominal transfer function is linear between the minimum transmission of 0.4% to the maximum transmission of 40%. During the first five coverage cycles, periodic adjustments were made to improve the slope and linearity of this transfer characteristic.

Figure 6

EXAMPLE OF POOR RADIOMETRIC TRANSFER FUNCTION

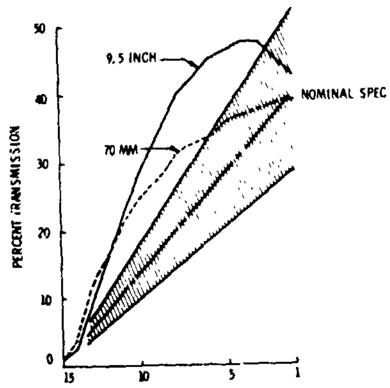


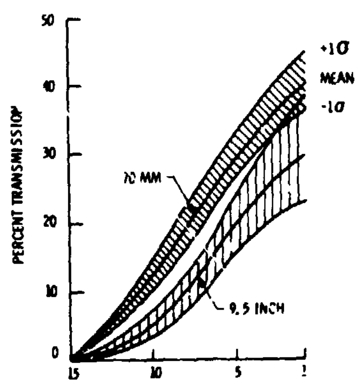
Figure 6 shows one of the poorer transfer characteristics measured on an image obtained during the second coverage cycle. The high slope and bow have the effect of causing positives to be generally lighter and negatives generally darker, than the nominal. Further, for the 9.5 inch imager, there is a portion of the dynamic range which is double valued, which renders this part of the range useless for radiometric purposes; fortunately, however, measurements show that little image data (except for clouds) fall into the upper part of the dynamic range.

Figure 7 shows the average transfer function as it now exists, measured over ten differnet days of the first months of '73. The mean and one sigma dispersion in the transfer characteristics are shown. The linearity, average slope and dispersion for the 70 mm imagery is excellent. For 9.5 inch imagery, the transfer characteristic is somewhat below nominal, but double valued regions have been eliminated.

Figure 7

CURRENT RADIOMETRIC TRANSFER FUNCTION

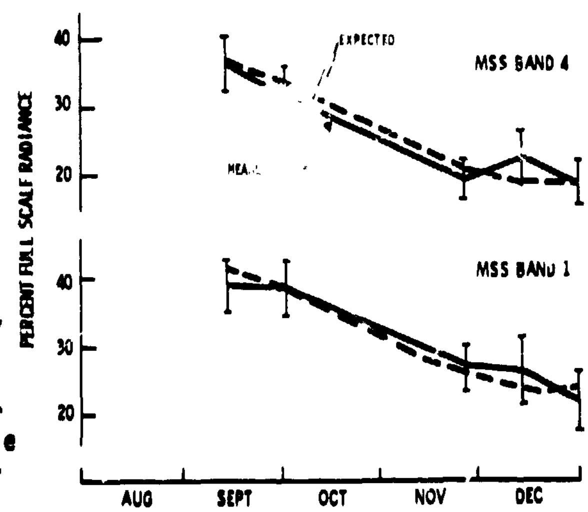
(MEAN AND STANDARD DEVIATION FOR MEASUREMENTS ON 10 DIFFERENT DAYS)



Radiometric Accuracy and Stability. Because of the intervening effects of the atmosphere, a good direct measure of the absolute radiometric accuracy or its stability is not available. Two approaches toward indirectly measuring stability of the system radiometric calibration for MSS data were investigated -- one using repetitive observations of the same areas; the other by monitoring the sun calibration data periodically taken.

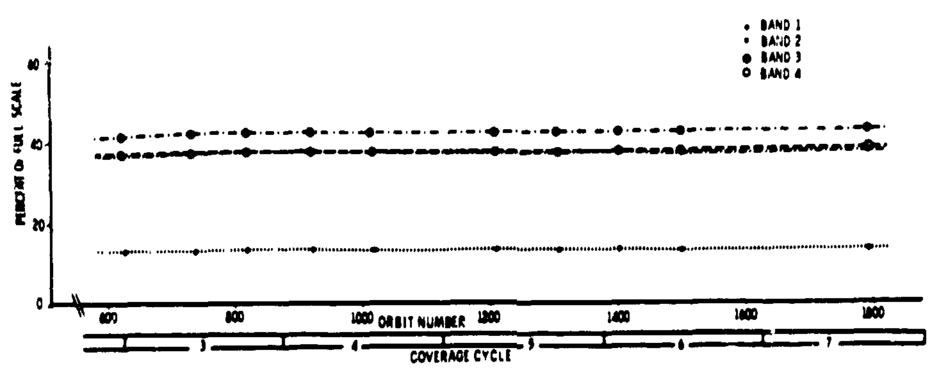
Imagery of relatively inert areas (in the vicinity of Death Valley, California) where surface reflectivity is assumed to be homogenous and constant, were observed on successive coverage cycles. The mean radiance from many targets in each observation was computed and plotted. The solid lines of Figure 8 connect these points for band 1 and band 4. The dashed lines show the expected change in radiance caused by seasonal illumination changes. Agreement is reasonable and within the uncertainty of the individual measurements; however, the number of sets of cloud free images and the time periods over which repetitive imagery was available was sufficiently short that quantitative conclusions are not warranted.

Figure 8
RADIANCE HISTORY
(DEATH VALLEY AREA)



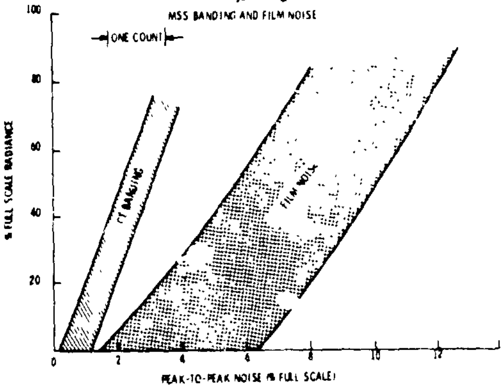
One each orbit the MSS can image the solar disk through a small aperture and reflecting mirror. Periodic observations of the sun calibration data for the MSS are shown in Figure 9. The calibrated sun data in all bands remains relatively flat, indicating stable system radiometric calibration within a few percent.

Figure 9
MSS SUN CAL HISTORY



MSS Banding. MSS computer compatible tapes were analyzed to determine the effectiveness of the relative detector-to-detector calibration. That is, to determine how much variation from scan-line to scan-line (detector-to-detector) exists over a uniform portion of an image. Data was evaluated at different radiance levels, in all spectral bands, and from CCT's obtained at different times. The results are plotted as the broad shaded curve in the left part of Figure 10. This plot is the peak-to-peak difference between any of the detectors in a band versus the mean level in that band.

Figure 10
MSS BANDING AND FILM NOISE



It is interesting to note that at low radiance levels the peak-to-peak banding amounts to only about 1% (half a quantum level) and increases with increasing radiance. In film images, however, banding is visible to the eye principally at low radiance levels and not at the higher levels. This is because of the eye's sensitivity to the higher contrast ratio at these low levels and because of other sources of "banding" in film images.

The right hand portion of Figure 10 represents the peak-to-peak value of all "system noise" as measured on film with a microdensitometer. Since the microdensitometer scans were made with a narrow but long slit with the long dimension parallel to the scan lines, this noise will include nonuniformities produced in film image generation, certain photographic nonuniformities as well as the inherent detector banding of the MSS. Note that Figure 10 is plotted in terms of peak-to-peak noise; RMS noise would be about four times smaller.

SUMMARY COMMENTS

The foregoing analyses leads to the general conclusion that the quality of the system corrected products produced by the ERTS-1 system during its initial period of operations is, from a resolution and radiometric accuracy viewpoint, quite consistent with prelaunch estimates. In the geometric sense, these data products are somewhat better (and in a few cases considerably better) than prelaunch estimates.

Another independent, but perhaps more subjective, measure of data quality was obtained from a questionnaire mailed to all principle investigators The investigators were asked to give their evaluation of the data products with respect to the prelaunch estimates they were provided. The responses are plotted in Figure 11 and show, perhaps, and even better report card than the more quantitative evaluation of this paper.

Figure II
USER QUESTIONNAIRE RESULTS