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REMOTE SENSOR COMPARISON FOR CROP AREA ESTIMATION

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INTRODUCTION: The National Agricultural Statistics Service (NASS) initiated this comparison of remote sensors to select a replacement for the Multispectral Scanner (MSS) LANDSAT data. NASS used MSS data in the crop area estimation program during the 1980 - 1987 time period. The operational remote sensing program processed between 70 and 90 LANDSAT MSS scenes per year. Ground truth data is combined with MSS data and processed through the USDA's PEDITOR system. Output from the PEDITOR system for each sampled unit, or segment, is the number of pixels classified to each cover. Reported acres for a crop in each sample segment, y_i the dependent variable, is combined with the classified number of pixels for a crop, x_i the auxiliary variate, to produce a regression estimator of total crop acres in a Landsat scene. Appendix A lists the formulas used to calculate total crop acres and the estimated variance for the total crop acres in one stratum.

Remotely sensed data types included in the comparison were LANDSAT Thematic Mapper (TM), French SPOT, and LANDSAT MSS data. MSS data were used as a comparison base. The choice of the "best" satellite type was based on the statistical performance of the regression estimator. This is different than most other remote sensing studies, in which percent correct classification is often used. It should be noted that the only product produced from the satellite data is an estimate of crop area and its estimated variance. The regression estimator needs the property of consistent classification to provide a reliable estimate. Thus, the NASS remote sensing program is looking for a data type that provides the most consistent classification. Other operational considerations are reviewed in this paper.

GROUND TRUTH, COVERAGE DATES, STUDY AREA: The study site was the Garden City area of western Kansas. The study included parts of Lane, Ness, Finney, Hodgeman, Gray, Ford, Meade, and Clark counties. The agricultural crop of interest was hard red winter wheat. Other prominent covers included pasture, fallow and bare soil. Overpass dates of the three sensors varied from April 20 to May 11, 1986. The SPOT scenes had overpass dates of May 1 or May 11. The TM scenes had overpass dates of April 20 and May 6. The MSS scenes had an overpass date of April 28. The different date combinations were grouped to produce three analysis areas or "analysis districts." See APPENDIX B for an overview of the study area, scene row/path, scene dates, locations and analysis district groupings.

Ground truth information is collected as a part of the June Enumerative Survey, an annual area-frame based sample survey. Ground data was from 234 sample segment sites in the eight county region. Each county is stratified into six land use strata. Two urban strata were excluded from the analysis due to small sample size and minimal crop presents. Another stratum, the rangeland stratum, had a target segment size of four square miles. The rangeland segments were included in the training process but were excluded from statistical analysis due to the small sample size and lack of crop of interest. The remaining three strata definitions were greater than 75 percent cultivated, 50 - 75 percent cultivated, and 25 - 50 percent cultivated. These three strata had target segment sizes of one square mile. As noted earlier, during the operational program segments are surveyed during June. For this study, however, administrative records from the USDA were used for the crop acreage and field boundaries. The administrative records kept by the Agricultural Stabilization and Conservation Service list by field the program crop participation. Any errors in ground truth data are consistent in all three sensors. That is, as noted above, the y_i, reported crop acreage per segment, is the same for all three sensors.

OPERATIONAL CONSIDERATIONS FOR THE NEW SENSORS: A primary operational consideration is the increased processing requirements of SPOT and TM due to the increased data volume. The MSS scenes were processed on a rented mainframe and a Cray supercomputer. NASS is currently converting to a new processing environment. The new processing environment will network PC's and supermicros, VAX and SUN computers, and will include a link to a Cray supercomputer.

The amount of data from TM and SPOT is about seven times the amount of data from MSS for a given land area. One MSS pixel has 4 data points or 4 band readings. For SPOT to cover the same ground area as one MSS pixel it requires 27 data points, 3 channels X 9 SPOT pixels per MSS pixel. For TM, 28 data points are required, 7 channels X 4 TM pixels per MSS pixel, to cover the same ground area as MSS's 4 data points. One example of additional computer resource requirements is the Maximum Likelihood Classification program. CPU requirements for Maximum Likelihood Classification is a constant X number of channels X number of categories X number of pixels. In addition to the increased data volume, NASS's clustering method creates more categories with both TM and SPOT. Without care one could easily use 14 to 21 times the computer resources used for MSS.

A caveat about directable satellites is the number of looks per repeat cycle may be deceiving. If the study area is greater than a path (two paths for SPOT) the effective number is one look per nadir orbit. Thus programable satellites lose their advantage over non-pointables when there is a large continuous study area or a short time window.

Tape handling and file maintenance could become operationally difficult when compared to MSS. Ninety MSS tapes would translate into 270 TM tapes and as many as 810 SPOT tapes. An analysis district is created from adjacent scenes for a specific date. The number of analysis districts for TM should not exceed the number for MSS. The number of analysis districts for SPOT would approximately triple, thus tripling the number of files.

The basic aggregation unit used in the operational program with MSS was a county. When a scene splits a county, additional processing is required. SPOT scenes, which are smaller than MSS or TM scenes, require much more splitting of county masks and adjustment of frame units. Mask splitting and frame unit adjustment are machine and labor intensive. Much care must be used to maintain the integrity of the frame. The work is directly proportional to the number of splits.

Registration of SPOT may be accomplished by using the five points furnished to calculate first order registration parameters. MSS and TM require labor intensive map to image registration. Local registration of SPOT is conducted using the usual shifting method. Larger number of boundary pixels must be pulled for SPOT as the shifts tend to be the same magnitude with respect to the earth as MSS and TM.

ANALYSIS: The statistical analyses determined whether there were significant differences between the accuracies of the regression estimates produced by the three sensors. If the mean absolute value of the residuals from a regression with data from sensor A were less than the mean absolute value of residuals from sensor B, then sensor A would produce more accurate regression estimates. Linear regressions were performed by land use stratum within analysis district. So, there were nine models, three analysis districts X three strata, estimated for each of the three sensors. Since the ground truth are identical across sensors, the absolute value of residuals could be compared in the statistical analysis.

The first test was an analysis of variance. The null hypothesis was that there was no significant difference between the means of absolute values of the residuals from TM, SPOT and MSS regressions. To increase the power of the test for sensor effect, the variation in absolute residuals due to the analysis district, the stratum, the interaction between stratum and analysis district and segment within analysis district was blocked. Land use strata were created independently of analysis districts and are thus not nested within analysis district. The following treatments were tested with the F-statistic against the remaining error in the model: sensor, sensor-analysis district (sensor*AD) interaction, and sensor-stratum interaction. There were a total of 181 segments and thus 543 observations. The ANOVA table is shown below.

ANALYSIS OF VARIANCE TABLE
FOR THE EFFECT OF SENSOR ON ABSOLUTE VALUE OF RESIDUALS

Source	DF	Sum of Squares	Mean Square	F	Pr>F
Analysis district	2	6506.11	3253.06		
Stratum	2	2262.59	1131.30		
Stratum*AD	4	22490.69	5622.67		
Segment (Analysis District Stratum)	172	607172.44	3530.07		
Sensor	2	32161.74	16080.87	16.42	.001
Sensor*AD	4	6396.85	1599.21	1.63	.165
Sensor*Stratum	4	6952.93	1738.23	1.77	.133
Error	352	344740.80	979.38		
TOTAL (Corrected)	542	1028684.15	3599.70		

The sensor effect was significant at alpha = .01, and the interaction effects were not significant. This made it possible to determine which sensor had the smallest absolute values of residuals. The mean absolute residuals from TM, SPOT and MSS were 38.39, 55.76 and 53.41, respectively. The values for SPOT and MSS were close, and the choice of future sensor is between SPOT and TM. Consequently, a t-test was conducted in which SPOT and TM absolute residuals were paired by segment. The alternative hypothesis was that TM produced smaller absolute residuals than SPOT. The mean value of the difference over 181 observations was 17.376, the standard error was 3.224 and the t-statistic was 5.389. The null hypothesis of no significant difference was rejected.

CONCLUSION: Given both the statistical analysis and operational considerations TM data is preferred to SPOT for crop area estimation. The TM data produces the most statistically accurate regression estimates and requires less analysis time than SPOT.

APPENDIX A: REGRESSION ESTIMATOR (GROUND DATA AND CLASSIFIED SATELLITE DATA) FOR A STRATUM IN AN ANALYSIS DISTRICT AND THE ESTIMATE OF THE VARIANCE FOR THE STRATUM

$$\hat{y} = N[\bar{y} + b(\bar{X} - \bar{x})]$$, where :

N = The number of sampling units in the stratum.

$\bar{y}$ = The June Enumerative sample average reported crop acres in the stratum.

b = The estimated regression coefficient for the stratum.

$\bar{X}$ = The average classified crop pixels for the stratum, total classified pixels divided by total units.

$\bar{x}$ = The average sample classified crop pixels for the stratum, sample classified pixels / sample units.

$$\hat{\sigma}^2 = N^2 * (1 - n/N) * \left[\frac{\Sigma(y_i - \bar{y})}{(n-2)}\right] * (1 - R^2) * \left[1 + \frac{1}{(n-3)}\right]$$

APPENDIX B: APPROXIMATE LOCATION OF SENSOR SCENES AND ASSOCIATED DATES IN RELATION TO EIGHT COUNTIES IN WESTERN KANSAS.

ANALYSIS DISTRICTS