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# DEVELOPMENT, TEST AND EVALUATION OF A COMPUTERIZED PROCEDURE FOR USING LANDSAT DATA TO ESTIMATE SPRING SMALL GRAINS ACREAGE

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ABSTRACT

This paper describes the development, test, and evaluation of CAESAR, a computerized area estimation technique recently tested at the NASA Johnson Space Center.

The technique utilizes decision logic to test for characteristics determined by analysts to be important for crop identification. Registered Landsat multispectral scanner data which have been transformed into Kauth-Thomas greenness and brightness are required.

The accuracy of proportion estimates obtained using CAESAR was comparable to earlier results using manual techniques which were very labor-intensive. The primary sources of error were the selection of acquisitions and the designation of biowindows. With correct acquisition selection/designation, the mean error was reduced from 3.01 percent to 1.36 percent, and the standard deviation was lowered from 11.31 percent to 6.19 percent. These results are similar to those observed during development and serve to illustrate the potential of the technique.

## I. INTRODUCTION

Since the first Landsat was launched in 1972, various methods have been developed which utilize data from the multispectral scanner (MSS) to provide information concerning crop acreages. Although very successful in many respects, most of these techniques are more labor-intensive than desirable. Efforts toward more objective and automated decision logic recently resulted in a procedure that requires no analyst activity and that can be used to estimate spring small grains acreage. The performance characteristics of the procedure were evaluated in an experiment at the NASA Johnson Space Center (JSC) during 1981.[1] The development, test, and evaluation of this procedure are described in this paper.

During the Large Area Crop Inventory Experiment (LACIE, 1975-77), several procedures were implemented to obtain proportion estimates for sample segments.[2] Although results were accurate enough to satisfy the goals of the experiment,[3] they relied heavily on execution by well-trained analysts and an intricate system of quality assurance and teamwork. Following the LACIE, efforts were directed toward making the procedures more objective.

In 1980, the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) program was initiated. The program consists of eight projects, each having a specific set of objectives. One of the objectives of the program's Inventory Technology Development (ITD) project is to improve the efficiency of analysis through increased automation. The CAESAR technique[4] was developed to support this goal.

Input data for this hierarchical procedure consist of from three to eight Landsat acquisitions collected over a 5- by 6-nautical-mile segment (196 pixels by 117 lines). The Kauth-Thomas[5†] transformation is applied to the four-channel Landsat data prior to application of the procedural logic.

The decision logic used in CAESAR is a slightly modified version of that developed for the Augmentation to the Reformatted Spring Small Grains Labeling Procedure.[6] It is designed to

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†The end products of this transformation are numeric values of greenness, brightness, yellowness, and nonesuch. The greenness value is stabilized by subtracting the greenness of bare soil from the greenness assigned to each pixel. The result is the green number, and it is the temporal variance of this value which sets the thresholds for the spring small grains logic used in the CAESAR procedure.

test for characteristics determined by analysts to be important for crop identification. This logic is applied to each of 836 pixels whose position within the segment is defined by a fixed grid. The proportion of spring small grains in the segment is determined by computing a simple random estimate based upon the temporal labels assigned to each pixel.

Acquisition selection/designation for the procedure is accomplished by utilizing a growing degree day meteorological model. This model, in essence, divides the spring small grains growing season into 10 specific periods, whose boundaries are expressed in terms of Julian days. Each available acquisition is then assigned to its respective period. During development, this was observed to be one of the most difficult tasks involved in the automation of the CAESAR procedure. For this reason, in testing, the procedure was executed in a semiautomatic mode, with acquisitions selected by an analyst, and was also executed in a completely automatic mode, with acquisitions as selected/designated by the model. This semiautomatic CAESAR was termed SSG-3B, and the automatic CAESAR, SSG-3C. The two procedures are identical in all other respects.

## II. STUDY SITE

Segments processed in the 1981 U.S./Canada Spring Small Grains Pilot Experiment were located in the States of Minnesota, North Dakota, South Dakota, and Montana and the Canadian Province of Saskatchewan. This region was chosen as representative of the Spring Wheat Belt of North America and is diverse in climate, physiography, and farming practices. For example, the eastern one-half of this belt is characterized by a temperate climate, deep, fertile soils, and a level to gently undulating topography. These factors favor intensive agricultural practices. Conversely, because of the semiarid climate of the western one-half of this region, the soils are usually thinner and contain less organic matter. Cultivation practices also differ. To conserve water, much of the tilled land is planted in alternating strip fields, usually small grains. The fields separating the small grains are fallow. The topography varies from level to steeply sloping, and vast acreages of land are used as range.[7,8]

All segments within the study site for the years 1976 through 1979 were considered to be candidates for processing if they had available both ground-truth data and at least two acquisitions within a crop year. Additional North Dakota segments without ground truth were processed for crop year 1978 in order to have a greater number of segments for use in a state-level aggregation.

The processability rates of the CAESAR procedure versus the historical state-of-the-art proportion estimation procedures are shown in table 1. Overall, the SSG-3C (CAESAR-based) procedure has a lower processability rate than the previous labor-intensive technique, 47.1 percent as compared to 76.1 percent, respectively. However, a 10.3 percent increase in processability occurs with the implementation of the analyst acquisition designation mode of the (CAESAR-based) SSG-3B technique. One seemingly standout year in terms of CAESAR processability is 1978. This anomaly may be explained by the launching of Landsat-3 in March of 1978. At this time, Landsat-2 was still in operation and the dual satellite coverage yielded many more acquisitions for processing.

Table 1. Processability Rates of CAESAR Versus Historical Procedures.

| Date | Historical* | CAESAR | | n |
|---|---|---|---|---|
| | | SSG-3B | SSG-3C | |
| Overall years | 252<br>76.1% | 190<br>57.4% | 156<br>47.1% | 331 |
| 1976 | 48<br>82.8% | 34<br>58.6% | 24<br>41.4% | 58 |
| 1977 | 61<br>68.5% | 39<br>43.8% | 28<br>31.5% | 89 |
| 1978 | 112<br>78.3% | 100<br>70.0% | 91<br>63.6% | 143 |
| 1979 | 31<br>75.6% | 17<br>41.5% | 13<br>31.7% | 41 |

LEGEND

SSG - Spring small grains
n - Number of acquisitions

*Historical Procedures

1976 - Phase II Detailed Analysis Procedure
1977 - Phase III Detailed Analysis Procedure
1978 - Transition Year (TY) Spring Small Grain Detailed Analysis Procedure
1978 - Saskatchewan Study Detailed Analysis Procedure
1979 - Exploratory Experiment Detailed Analysis Procedure (1980)

In table 2, the test results of the SSG-3 procedures are compared to earlier techniques. In evaluating the performance of the CAESAR techniques, it was necessary to assess each procedure independently for each year. The segments used in this evaluation are not identical in number or location; however, it is possible to make an indirect comparison of the CAESAR and labor-intensive procedures. Overall, the SSG-3 procedures proved comparable in performance to the manual procedures, with consistently smaller mean errors and larger standard deviations. Graphic comparisons of the SSG-3C and SSG-3B spring small grains proportion

Table 2. Proportion Estimation Results of CAESAR Versus Historical Procedures.

| Statistic | All years | | 1976 | | 1977 | | 1978 | | 1979 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SSG-3C | SSG-3B | SSG-3C | SSG-3B | SSG-3C | SSG-3B | SSG-3C | SSG-3B | SSG-3C | SSG-3B |
| $\bar{e}$ | 1.55 | 3.01 | 4.56 | 5.62 | 2.76 | 2.12 | -1.04 | 0.04 | 3.80 | 7.71 |
| $S_e$ | 12.65 | 11.31 | 9.10 | 6.72 | 12.09 | 9.51 | 11.52 | 11.12 | 19.05 | 16.23 |
| MAE | 9.94 | 8.49 | 7.89 | 6.16 | 9.81 | 7.73 | 9.01 | 8.44 | 15.75 | 12.66 |
| RME | 5.72 | 11.51 | 16.70 | 24.10 | 10.04 | 8.20 | -3.90 | 0.15 | 13.77 | 25.30 |
| $\bar{p}$ | 27.10 | 26.16 | 27.31 | 23.32 | 27.48 | 25.85 | 26.66 | 26.04 | 27.60 | 30.47 |
| n | 112 | 144 | 21 | 30 | 25 | 37 | 50 | 53 | 16 | 24 |

| Statistic | Phase II | Phase III | TY 1978 | | 1980 SSG |
|---|---|---|---|---|---|
| | 1976 | 1977 | U.S. | SK. | Exploratory |
| e | -5.51 | -6.10 | -4.0 | -2.9 | -3.5 |
| $S_e$ | 8.52 | 5.40 | 7.40 | 7.36 | 5.9 |
| RME | -24.51 | -17.48 | -13.94 | -6.8 | -11.9 |
| n | 35 | 45 | 38 | 15 | 35 |

Mean error: $$\bar{e} = \sum_{i=1}^{n} (\hat{P}_i - P_i)/n \quad = \frac{1}{n}\sum_{i=1}^{n} e_i$$

Standard deviation of errors: $$S_e = \left[\sum_{i=1}^{n} (e_i - \bar{e})^2/n - 1\right]^{1/2}$$

Mean absolute error: $$MAE = \sum_{i=1}^{n} |e_i|/n$$

Mean ground truth: $$\bar{p} = \sum_{i=1}^{n} P_i/n$$

Relative mean error (%): $$RME = \bar{e}/\bar{p} \times 100$$

$\hat{P}_i$ = proportion estimate for $i^{th}$ observation (%)

$P_i$ = ground truth proportion for $i^{th}$ observation (%)

$e_i$ = proportion error for $i^{th}$ observation = $\hat{P}_i - P_i$

n = number of observations

estimates versus ground-truth proportions are shown in figures 1 and 2.

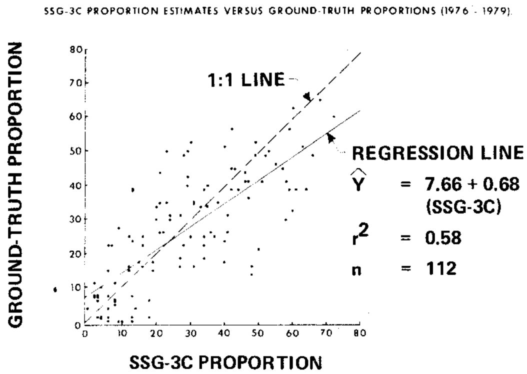


Figure 1. SSG-3C Proportion Estimates Versus Ground-Truth Proportions (1976-1979).

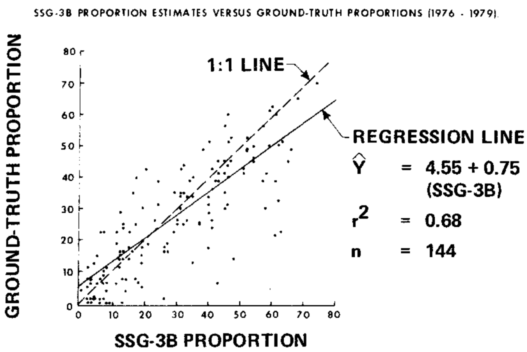


Figure 2. SSG-3B Proportion Estimates Versus Ground-Truth Proportions (1976-1979).

## III. AGGREGATION TECHNOLOGY/RESULTS

The baseline aggregation component used to determine large-area (state-level and higher) estimates of crop acreages during the pilot experiment is a two-phase system, consisting of a stratum-level subcomponent and an above-stratum-level subcomponent. A stratum is defined as a (relatively small) subportion of the target region whose cropping intensity is more homogeneous than that of the entire target region. The stratum-level subcomponent accepts segment crop proportion estimates (e.g., from CAESAR) as inputs and generates a single estimate of the crop acreage for each stratum represented in the sample (of segments with proportion estimates) by at least one segment. The acreage estimate for each stratum is also accompanied by an estimate of variability. The above-stratum-level subcomponent utilizes the outputs from the the first stage and stratum-level government statistics on harvested crop acreages from several previous years. These historical government crop data are used to arrive at ratio estimates of the current-year crop acreages for those strata not represented in the sample of segments that have usable processing results. The ratio estimation is performed in a manner that minimizes the estimate of variance for the entire region's crop area estimate. The region's crop acreage estimate is determined by summing the area estimates for the individual strata. A detailed technical description of this procedure is provided by Chhikara and Feiveson.[9,10,11]

The aggregation test of the SSG-3 procedures was conducted using the 1978 segment processing results for North Dakota. The results are shown in table 3. For the purpose of aggregation, North Dakota was divided into four strata, representing regions of (historically) homogeneous small grains production,[12] and a total of

Table 3. North Dakota Aggregations: Area Estimation Results.

| Procedure | Estimate (1000's) | "Observed" error (1000's) | Standard error (1000's) | Relative error | Coefficient of variation | Number of segments |
|---|---|---|---|---|---|---|
| SSG-3B/SFG-1 | 13,572.84 | 452.84 | 582.92 | 3.45% | 4.44% | 62 |
| SSG-3C/SFG-1 | 14,026.48 | 906.48 | 558.79 | 6.91% | 4.26% | 56 |
| LACIE/SFG-1 | 11,962.46 | -1157.54 | 488.07 | -8.82% | 3.72% | 76 |

USDA standard = 13,120.0

SSG-3B = Semiautomatic CAESAR

SSG-3C = Automatic CAESAR

LACIE = Spring Small Grain Detailed Analysis Procedure used in TY

SFG-1 = Spring Small Grain Baseline Aggregation Technology

94 segments were identified as candidates for processing. For the aggregations, the U.S. Department of Agriculture (USDA) historical data for 1977 were used in ratioing, with the data for 1972 through 1976 serving as support.

The final aggregated estimate of spring small grains corresponding to SSG-3C was 14,026,480 acres, with a standard error of 558,790 acres (4.26 percent) and a relative error of 906,480 acres (6.91 percent). The respective figures for the SSG-3B processings were 13,572,840 acres, 582,920 acres (4.44 percent), and 452,840 acres (3.45 percent). The 1978 USDA-reported spring small grains harvest for this region was 13,120,000 acres. Aggregation of the 76 available LACIE Transition year (TY) proportion estimates for North Dakota yielded an estimate of 11,962,460 acres, with a standard error of 488,070 acres (3.72 percent) and a relative error of -1,157,540 acres (-8.82 percent). Hypothesis tests at 0.05 significance level indicate the following:

1. The large-area spring small grains estimates corresponding to both SSG-3C and SSG-3B processings are not significantly different from the USDA standard.

2. The aggregation of the LACIE-TY processings resulted in a negatively biased estimate.

3. The large-area estimates corresonding to both SSG-3C and SSG-3B are significantly different from the LACIE-TY processings of 1978.

## IV. ERROR CHARACTERIZATION

Review of segment-level performance of the SSG-3 procedures produced the expected result that acquisition selection/designation was the major source of error. Problems due to the meteorological model were encountered on about one-half of the segments processed. Many of these errors were corrected during the acquisition verification for the semiautomated processings of the pilot experiment. Those remaining were rerun with the proper acquisitions during the error characterization. Some of the segments with the most dramatic reductions in error are shown in table 4.

Acquisition changes were made on 27 percent of the segments processed. No changes were made to the CAESAR spring small grains decision logic. Table 5 and figure 3 show the results of

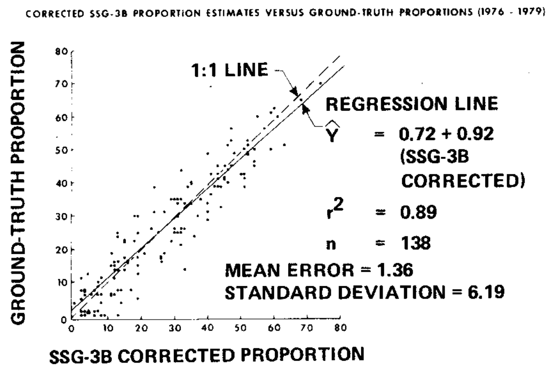


Figure 3. Corrected SSG-3B Proportion Estimates versus Ground-truth Proportions (1976-79).

Table 4. Improvement in Segment Proportion Estimates When Acquisition Designation is Corrected.

| Segment number | Crop year | Ground-truth proportion | Acquisitions selected/designated using meteorological model | | Correct acquisitions | |
|---|---|---|---|---|---|---|
| | | | Proportion estimate | Absolute error | Proportion estimate | Absolute error |
| 1920 | 1979 | 21.1 | 50.4 | 29.3 | 31.9 | 10.8 |
| 1392 | 1979 | 29.9 | 58.3 | 28.4 | 18.2 | -11.7 |
| 3050 | 1979 | 32.8 | 60.4 | 27.6 | 43.7 | 10.9 |
| 3185 | 1978 | 49.4 | 22.6 | -26.8 | 53.8 | 4.4 |
| 1394 | 1979 | 39.1 | 13.5 | -25.6 | 34.0 | -5.1 |
| 1903 | 1977 | 17.1 | 40.1 | 23.0 | 26.0 | 8.9 |
| 1633 | 1976 | 39.3 | 61.2 | 21.9 | 44.0 | 4.7 |
| 3130 | 1979 | 52.2 | 30.4 | -21.8 | 47.2 | -5.0 |
| 1550 | 1978 | 0.6 | 18.5 | 17.9 | 1.9 | 1.3 |
| 1619 | 1978 | 48.2 | 65.8 | 17.6 | 47.7 | -0.5 |
| 1461 | 1978 | 40.8 | 57.7 | 16.9 | 45.1 | 4.3 |

Table 5. Proportion Estimates: SSG-3B$_1$ (Pilot) Versus SSG-3B$_2$ (Error Characterization).

| Statistic | All years | | 1976 | | 1977 | | 1978 | | 1979 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SSG-3B$_1$ | SSG-3B$_2$ | SSG-3B$_1$ | SSG-3B$_2$ | SSG-3B$_1$ | SSG-3B$_2$ | SSG-3B$_1$ | SSG-3B$_2$ | SSG-3B$_1$ | SSG-3B$_2$ |
| $\bar{e}$ | 3.01 | 1.36 | 5.62 | 3.98 | 2.12 | 2.30 | 0.04 | -0.59 | 7.71 | 1.17 |
| $S_e$ | 11.31 | 6.19 | 6.72 | 4.13 | 9.51 | 5.54 | 11.12 | 6.46 | 16.23 | 7.46 |
| MAE | 8.49 | 5.14 | 6.16 | 4.54 | 7.73 | 4.99 | 8.44 | 5.19 | 12.66 | 6.07 |
| RME | 11.51 | 5.16 | 24.10 | 16.80 | 8.20 | 8.65 | 0.15 | -2.27 | 25.30 | 3.88 |
| $\bar{p}$ | 26.16 | 26.34 | 23.32 | 23.68 | 25.85 | 26.59 | 26.66 | 26.04 | 30.47 | 30.19 |
| n | 144 | 138 | 30 | 29 | 37 | 34 | 53 | 53 | 24 | 22 |

| Statistic | Phase II 1976 | Phase III 1977 | TY 1978 U.S. | TY 1978 SK. | 1980 SSG Exploratory |
|---|---|---|---|---|---|
| $\bar{e}$ | -5.51 | -6.10 | -4.0 | -2.9 | -3.5 |
| $S_e$ | 8.52 | 5.40 | 7.40 | 7.36 | 5.9 |
| RME | -24.51 | -17.48 | -13.94 | -6.8 | -11.9 |
| n | 35 | 45 | 38 | 15 | 35 |

replacing the original proportion estimates for these 39 segments with the new estimates.

As is evidenced in table 5, substantial improvement occurs with correct acquisition selection/designation. Overall, mean error is reduced from 3.01 percent to 1.36 percent, standard deviation from 11.31 percent to 6.19 percent, and mean absolute and relative mean errors from 8.49 percent and 11.51 percent to 5.14 percent and 5.16 percent, respectively. A visual appreciation of the overall amelioration to the semiautomated CAESAR results can be provided by figure 3. Here, the fit of the data to the 1:1 line is tighter than the previous SSG-3B results revealed in figure 2, and the $r^2$ value at 0.89 is much higher than the 0.68 of the pilot experiment. When compared to the manual state-of-the-art procedures, the semiautomated CAESAR technique (SSG-3B$_2$ results) produces consistently lower mean absolute errors, comparable standard deviations, and much lower relative mean errors. These SSG-3B$_2$ results are similar to those observed during the development of the CAESAR technique.

## V. CONCLUSIONS

An automatic area estimation procedure, CAESAR, has been developed for the spring small grains region of North America. The technique is highly efficient and produces accurate results. Segment-level estimation and regional area estimation are comparable to the best pre-AgRISTARS spring small grains procedures. Error characterization results illustrate the potential of the technique by suggesting that even better performance is readily obtainable, given correct acquisition selection/designation. Expansion to include other crop types and adaptation to foreign countries appear to be the next logical steps in further development of this technique.

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