National Mapping Program

Determination of the Total, Commonality, and Uniqueness of Interpreted Structural Elements from Remotely Sensed Data in Alaska

Open File Report 83-876
1983

U.S. Department of the Interior
Geological Survey
National Mapping Division
Office of Geographic and Cartographic Research

UNITED STATES
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

DETERMINATION OF THE TOTAL, COMMONALITY, AND UNIQUENESS OF INTERPRETED STRUCTURAL ELEMENTS FROM REMOTELY SENSED DATA IN ALASKA

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DETERMINATION OF THE TOTAL, COMMONALITY, AND UNIQUENESS OF INTERPRETED STRUCTURAL ELEMENTS FROM REMOTELY SENSED DATA

by George H. Rosenfield
U.S. Geological Survey
521 National Center
Reston, Virginia 22092

ABSTRACT

A remote sensing experiment was conducted to determine the unique value of real- and synthetic-aperture side-looking airborne radar (SLAR) in the detection of structural features. In this study SLAR was compared to standard and digitally enhanced Landsat multi-spectral scanner (MSS) images and to aerial photographs. Structural features thought to consist of anticlinal axes, synclinal axes and lineaments that were considered to be the surface expression of underlying faults or fractures were interpreted. Lineaments were subdivided into categories of "possible and probable faults or fractures." After interpretation of the imagery, the data were cumulated in two ways: (1) by total length in miles, and (2) by frequency of counts. For purposes of analysis, the data were considered to be within three domains of study: (1) a study comparing SLAR and Landsat images at a small scale over two large tracts of land in two different physiographic regions in Alaska; (2) a five-sensor overlap area study comparing SLAR and Landsat images at a large scale with aerial photographs, and (3) a two-sensor study, comparing only real- and synthetic-aperture SLAR images at a large scale. The length data were also compared for commonality between pairs of the various sensors in both the small-scale study and the five-sensor overlap area study. The concept of a "unique" (non-commonality) contribution was defined as the total number of miles the interpreted structural element contained minus the commonality miles.

Statistical analysis of the measured data was performed by using analysis of variance for the total miles and commonality miles of interpreted structural elements. After analysis for the total miles and commonality miles, the uniqueness miles were determined by subtraction, and a percentage of the total was computed. Statistical analysis of the frequency data was performed by using functions of categorical response as a linear model.

The maximum "uniqueness" for measurement of interpreted structural elements in Alaska, as determined from this experiment, is obtained from real-aperature SLAR, 58.3 percent of total, and secondly from digitally enhanced Landsat MSS images, 54.1 percent of total. Both these sensors measure the same number of total miles, although real-aperature SLAR measures less commonality miles than does enhanced Landsat. Aerial

photographs measure the same in all criteria as does real-aperture SLAR. Synthetic-aperture SLAR and standard Landsat measure less than the other three sensors.

1. INTRODUCTION

This statistical analysis was performed at the request of the Office of Earth Science Applications, U.S. Geological Survey using the data obtained from the study report of Pascucci and others (1981). The Pascucci report describes the study area, the types and coverage of the imagery, the interpretation of the imagery, the digitization of the interpreted data, and the map production and digital manipulation. In addition, the Pascucci report discusses the total information content in terms of structural elements interpreted of each sensor platform, the commonality of information contribution of each sensor, and the "unique", (noncommonality) incremental information contribution of SLAR, Landsat, and aerial photographs.

1.1 Background

The House and Senate Conference Report on H.R. 4930 (96th Congress), Department of the Interior and Related Agencies Appropriations, 1980 mandated that the U.S. Geological Survey should "begin the use of side-looking airborne radar (SLAR) imagery for topographic and geological mapping and geological resource surveys in promising areas, particularly Alaska." Accordingly, the USGS issued contracts to: (1) acquire SLAR imagery covering two areas in Alaska; and (2) evaluate and compare the geologic information content of the real- and synthetic-aperture SLAR imagery, and define the contribution of SLAR imagery to structural geologic mapping. Imagery from five different remote sensors was interpreted, quantified and compared using a computer-assisted geographic information system. The imagery that was examined consisted of real- and synthetic-aperture SLAR imagery at 1:250,000-scale, standard and digitally enhanced Landsat MSS imagery at 1:500,000-scale, and color aerial photographs at 1:80,000-scale. The study area included three U.S. Geological Survey quadrangles of the 1:250,000-scale map series: the Ugashik map in the Alaskan peninsula, and the Utukok River and Lookout Ridge maps in the North Slope and Brooks Range. SLAR imagery at enlarged scales of 1:100,000 and 1:50,000 were also interpreted for four sites within the Ugashik quadrangle to determine the extent to which the interpreted information content varied with scale. Structural features thought to consist of anticlinal axes, synclinal axes and lineaments that were considered to be the surface expression of underlying faults or fractures were interpreted. Lineaments were subdivided into categories of "possible and probable faults or fractures."

Upon completion of the image interpretation, overlays containing the interpretation results were digitized for entry into the geographic information system. The digital maps were then stored in the geographic data base in a form suitable for quick and efficient retrieval and analysis. Statistical data enumerated the total number and length of interpreted structured features shown on each map as well as measurements of "commonality" and "uniqueness" of each data set.

Pascucci and others (1981, p. 22, 25) indicate that the length of the overlapping portion of the interpreted features determined the length of "commonality" for each data set; and that by subtracting the total commonality length from the total length of interpreted structure for each data set, it was possible to determine the "uniqueness" of each data set.

The principal objectives of the contract study were to determine: (1) the unique incremental contribution by length and frequency of interpreted information for each data set, (2) the interpreted information content of the real- and synthetic-aperture SLAR imagery at a scale of 1:250,000, and (3) the effect of enlargement on the interpreted information content of the real- and synthetic-aperture SLAR imagery.

1.2 Purpose and Scope

The purpose of this study was to determine the "unique" contribution of SLAR imagery to mapping interpreted structural elements. Accordingly, the data have been analyzed for each sensor, first for total length (in miles), and next for the length (in miles) detected in common with other sensors. Following this, the commonality length for each sensor was extracted. After these data were analyzed, the uniqueness for each sensor was obtained. In addition, the total frequency (in counts) for each sensor was analyzed even though it did not enter into the uniqueness determination. For both the total length data study and the frequency data study, the data were analyzed separately by each of three domains of study: (1) a study comparing SLAR and Landsat images at a small scale over two large tracts of land in two different physiographic regions in Alaska, (2) a five-sensor overlap area study comparing SLAR and Landsat images at a large scale with areal photographs, and (3) a two-sensor study comparing only real- and synthetic-aperture SLAR images at a large-scale. For the commonality length data study, the data were analyzed only for the small-scale study and the five-sensor overlap area study because there were no commonality data measured for the large-scale study. The uniqueness determination was made for only the small-scale study and the five-sensor overlap area study.

For the frequency data study, the data were analyzed separately by each of the three domains of study: the small-scale study, the five-sensor overlap area study, and the large-scale study.

1.3 General

It must first be recognized that the data recorded by Pascucci and others (1981), and subsequently addressed in this report, are the result of subjective interpretations of remote sensing data. These data represent what are thought to be surficial expressions of selected structural features. Therefore, in the text of this report these selected features are called "interpreted structural elements". This does not imply that:

(1) the data necessarily represent the true structural geology of the area; or that (2) the data (either line miles or frequency data) represent the strike distribution of these data. The look direction of SLAR and the illumination angle for Landsat and aerial photographs would imply that these data sets do not represent the strike distribution. In addition, since the look directions of the two SLAR data sets are different in both areas of analysis, the uniqueness of these data may be related to the relationship of strike-to-look direction. Accordingly, this report is more important from the standpoint of statistical methodology for analyzing interpreted data of this type, then it necessarily is for any technological conclusions drawn from it. It is considered that the data are used only as an illustration.

2. DATA ANALYSIS AND RESULTS

2.1 Analysis Based on Total Interpreted Structural Elements Detected by Length (in miles)

Analysis of the number of linear miles of interpreted structural elements was performed by analysis of variance using the general linear model (GLM) procedure of the statistical analysis system (SAS) computer package (Helwig and Council, 1979). The major purpose of the analysis is to determine if there is a significant difference, at some acceptable probability level, among the sensor effects for use in detecting total length of interpreted structural elements. The null hypothesis to be tested is that the mean length effect of each sensor equals the mean length effect of each other sensor. The alternate hypothesis is that the mean length effects are not the same. The Duncan procedure of SAS, the Duncan multiple range test (Duncan, 1955) is used to determine which sensors are different from which others, when the mean effects are found to be significant. A secondary purpose is to determine the relationship among the effects of area, interpreted structural element, and (or) scale.

It must be pointed out that it is the same structural features that are being detected by each of the sensors. Accordingly, the observations are not rigorously independent. Cochran (1947, p. 32-33) states that the effects of correlation among the errors may result in substantial biases in standard errors, but that the difficulty is largely eliminated by proper randomization. According to Steel and Torrie (1960, p. 128-129), there is often good reason to believe that some or all of the assumptions are false. Such departure can affect both the level of significance and the sensitivity of such tests; and since most data do not exactly fulfill the requirements of the mathematical model, procedures for testing hypotheses and estimating confidence intervals should be considered approximate rather than exact. Thus, for marginally significant results, a smaller significance criterion should be used; for example, from 0.05 to 0.025.

The data for the analysis of variance are shown in tables 1 and 2. There is only one observation per cell for the analysis of variance, because there were no replications to the experiment. Accordingly, the highest order interaction cannot be determined, as that value contributes to the error effect. Any lower order interaction terms not included in

Table 1.--Total Interpreted structural elements detected by length (in miles) [Data from Pascucci and others, 1981 (Table VI, as modified)]

Area	Sensor	Small-scale interpreted structural elements by length				
		Probable fault or fracture	Possible fault or fracture	Synclinal axis	Anticlinal axes	Totals
Ugashik	Synthetic aperture SLAR	26	1,181	37	38	1,282
	Real aperture SLAR	102	1,443	0	0	1,545
	Standard Landsat MSS	0	478	0	0	478
	Enhanced Landsat MSS	0	1,047	26	29	1,102
Utukok River/ Lookout Ridge	Synthetic aperture SLAR	11	1,653	387	429	2,480
	Real aperture SLAR	99	1,903	676	795	3,473
	Standard Landsat MSS	48	1,194	506	549	2,297
	Enhanced Landsat MSS	104	2,475	511	561	3,651
Five-Sensor Overlap Area	Synthetic aperture SLAR	5	770	15	39	829
	Real aperture SLAR	2	769	173	185	1,129
	Standard Landsat MSS	3	595	117	109	824
	Enhanced Landsat MSS	37	967	78	127	1,209
	Aerial photos	0	1,038	47	38	1,123

Table 2.--Interpreted structural elements detected as a function of scale
[Data from Pascucci and others, 1981 (Table X)]

Sensor	Site	Scale (in 1,000's)	Large-scale interpreted structural element by length (miles)				
			Probable fault or fracture	Possible fault or fracture	Synclinal axis	Anticlinal axis	Totals
Synthetic Aperture SLAR	Deer Creek	1:250	-	-	-	-	65
		1:100	20	80	9	0	109
		1:50	0	96	10	0	106
	Wide Bay	1:250	-	-	-	-	32
		1:100	1	34	0	8	43
		1:50	2	64	0	0	66
	Salmon River	1:250	-	-	-	-	41
		1:100	0	52	0	0	52
		1:50	0	82	1	0	83
	Mt. Peulik	1:250	-	-	-	-	17
		1:100	0	22	0	0	22
		1:50	0	32	0	0	32
Real Aperture SLAR	Deer Creek	1:250	-	-	-	-	81
		1:100	0	52	0	0	52
		1:50	0	69	0	0	69
	Wide Bay	1:250	-	-	-	-	52
		1:100	2	25	0	9	36
		1:50	1	40	0	0	41
	Salmon River	1:250	-	-	-	-	36
		1:100	0	57	0	0	57
		1:50	0	57	0	0	57
	Mt. Peulik	1:250	-	-	-	-	54
		1:100	0	36	0	0	36
		1:50	0	39	0	0	39

the linear model also contribute to the error effect. The data were processed through the analysis of variance adjustment, first with the full interaction model. If none of the higher order interactions were found significant, the data were readjusted using a model with lower order interactions. The data were also first processed using all four interpreted structural elements: (1) probable faults or fractures; (2) possible faults or fractures; (3) synclinal axes, and (4) anticlinal axes. However, in all cases, the possible faults or fractures dominated the data set, and there are many cells with zero or small values for the other elements. Accordingly, the data were cumulated into suspected faults or fractures and suspected synclines/anticlines for a second processing. Finally, the data were further cumulated into totals of all interpreted structural elements for the last processing. This version of the paper will document only the adjustment finally selected for obtaining results and reaching conclusions.

A summary of the numerical results is given in table 3. In this table, the model F "tests how well the model as a whole (after adjusting for the mean) accounts for the dependent variable's behavior. If the significance probability, labelled $P>F$, is small, it indicates significance" (Helwig, 1978, p. 61). If $P>F<\alpha$ (α is a predetermined value for the significance level, usually 0.05.) the results are significant and the model well accounts for the dependent variable's behavior. If $P>F>\alpha$, the meaning is not significant, and the model does not account for the behavior. The coefficient of determination, R^2, measures how much variation in the dependent variable can be accounted for by the model (how well the model fits the data).

Table 3.--Values of significance probability and R^2 from analysis of variance of interpreted structural elements by length data.

						Smallest sensor effect
Model		Area	Sensor	Geology	Scale	2-Factor
$P>F$	R^2	$P>F$	$P>F$	$P>F$	$P>F$	$P>F$
			Small-scale study			
0.0277*	0.949	0.0066*	0.1700o			
			Five-sensor overlap area study			
Analysis of variance not used						
			Large-scale study			
0.0348*	0.928	0.0031*	0.3763		0.1307 o	0.0544 o

* Significant at $\alpha = 0.05$ probability level.
o Significant at $\alpha = 0.20$ probability level.

The remaining values of P>F measure the significance probability for the mean effect of the factor considered. If $P>F<\alpha$, the factor is deemed significant, and the null hypothesis is rejected. If $P>F>\alpha$, there is no evidence to reject the null hypothesis.

2.1.1 Small-Scale Study

Analysis of variance for this data set was performed with two levels of area, four levels of sensor, and one level (the totals) of interpreted structural elements. There are no cells with zero or small values, and the data are not unbalanced between types of interpreted structural elements. Previous computer runs indicated that there are no significant two-factor sensor interactions. The statistical model included only the main effects for area and sensor. The model, after adjustment for the mean, significantly accounts (0.0277) for the dependent variable's behavior, and accounts for 94.9 percent of variation in the dependent variable. The sensor effect is significant at the $\alpha=0.20$ probability level. The mean values for miles of interpreted structural elements from this test are:

2,509.0	Real-aperture SLAR
2,376.5	Enhanced Landsat
1,881.0	Synthetic-aperture SLAR
1,387.5	Standard Landsat

Duncan's multiple range test does not show any differences.

Snedecor and Cochran (1967, p. 28-29) indicate caution when interpreting significant results in a small sample experiment. They indicate that "with a small sample, the test is likely to produce a significant result only if the null hypothesis is very badly wrong." In this connection they advise to look at the confidence limits of the population at the desired probability level. In this regard, the 80-percent confidence limits were computed about the adjusted mean values for each of the sensors. On the basis of overlap of the 80-percent confidence limits it is seen that real-aperture SLAR, enhanced Landsat, and synthetic-aperture SLAR are not significantly different from each other; and that synthetic-aperture SLAR, standard Landsat, and (barely so) enhanced Landsat are also not significantly different from each other.

Therefore, it can be concluded from this test that the combination of real- and synthetic-aperture SLAR and enhanced Landsat imagery together, on the average, detect approximately 1.4 times more the number of linear miles of interpreted structural elements than does the combination of synthetic-aperture SLAR and standard Landsat MSS imagery together, on the average.

2.1.2 Five-Sensor Overlap Area Study

Analysis of variance for this data set cannot be used since the data consist of only one total value of interpreted structural elements for each of the five sensors, and there are no degrees of freedom for error. Since the data are approximately independently and normally distributed (except for the caution of Cochran, 1947, p. 24), the t-test was used to determine if the differences from the mean exceed the 80-percent confidence limits.

The total values for miles of interpreted structural elements for this test are:

1,209	Enhanced Landsat
1,129	Real-aperture SLAR
1,123	Aerial photographs
829	Synthetic-aperture SLAR
824	Standard Landsat

On the basis of this t-test, it is seen that real-aperture SLAR and aerial photographs are not significantly different from each other, and that synthetic-aperture SLAR and standard Landsat are also not significantly different from each other. Enhanced Landsat, however, is significantly different from the other two combinations of similar sensors:

(1) real-aperture SLAR and aerial photographs,
(2) Synthetic-aperture SLAR and standard Landsat.

Therefore, it can be concluded from the test that with 80-percent confidence: (1) the combination of real-aperture SLAR and aerial photographs together, on the average, detect approximately 1.4 times more the number of linear miles of interpreted structural elements than does the combination of synthetic-aperture SLAR and standard Landsat MSS imagery together, on the average; (2) enhanced Landsat MSS imagery detects approximately 1.46 times more the number of linear miles of interpreted structural elements than does the combination of synthetic-aperture SLAR and standard Landsat together, on the average.

2.1.3 Large-Scale Study

Analysis of variance for this data set was performed with four levels of area, two levels of sensor, three levels of scale, and one level (the totals) of interpreted structural elements. There are no cells with zero or small values, and the data are not unbalanced between types of interpreted structural elements. In addition, there are three scales of data available instead of two. The statistical model included the three main effects, and all two-factor interactions. The model, after adjustment for the mean significantly accounts (0.0348) for the dependent variable's behavior, and accounts for 92.8 percent of variation in the dependent variable. There are no significant two-factor sensor interaction effects at the $\alpha=0.05$ probability level. The sensor effect is not significant at the $\alpha=0.20$ probability level.

The mean values for miles of interpreted structural elements from this test are:

55.7	Synthetic-aperture SLAR
50.8	Real-aperture SLAR

The conclusion of the large-scale study is that both synthetic- and real-aperture SLAR detect the same number of linear miles of interpreted structural elements, and that the observed differences between them could have arisen by chance.

The general conclusion from the length data study is that at the small scales of 1:500,000 and 1:250,000, the combination of real-aperture SLAR, synthetic-aperture SLAR, and digitally enhanced Landsat MSS imagery together, on the average, detect approximately 1.4 times more the number of linear miles of interpreted structural elements than does the combination of synthetic-aperture SLAR and standard Landsat MSS imagery together, on the average. Aerial photographs at 1:80,000-scale detect approximately the same as real-aperture SLAR or digitally enhanced Landsat MSS imagery. At large scales of 1:50,000, 1:100,000, and 1:250,000 there is no significant difference between real- and synthetic-aperture SLAR for detecting the number of linear miles of interpreted structural elements, and that the observed difference between them could have arisen by chance.

2.2 Commonality of Interpreted Structural Elements Detected by Length (in miles)

Commonality of interpreted structural elements, or relative agreement between two (or more) data sources, reflects the overlap portion between sensors when the interpreted map sheets from one sensor are overlaid on those from another sensor. When this is done, a certain number of interpreted structural elements overlap one another for some specific length. The length of the overlapping portion of these features is the length of commonality for each data set (Pascucci and others, 1981, p. 22).

The data measured for commonality are given in table 4 for the small-scale study, and in table 5 for the five-sensor overlap area study. There were no commonality data measured for the large-scale study.

Table 4.--Commonality of interpreted structural elements detected by length (in miles) for small-scale study [Data from Pascucci and others, 1981, Table VIII, p. 32]

	Ugashik	Utukok River Lookout Ridge
Synthetic- and real-aperture SLAR	373	1,620
Synthetic-aperture SLAR and standard Landsat	89	1,290
Synthetic-aperture SLAR and enhanced Landsat	387	1,693
Real-aperture SLAR and standard Landsat	167	1,461
Real-aperture SLAR and enhanced Landsat	366	1,769

Table 5.--Commonality of interpreted structural elements detected by length (in miles) for five-sensor overlap area study [data from Pascucci and others, 1981, diagonal data from Table VIII, p. 32, non-diagonal data from figures 21, 22, 23, 24]

	1-3	1-4	1-5	2-3	2-4	2-5	3-4	4-5	1-3-4	1-4-5	2-3-4	2-4-5
1-3		302							57			
1-4			456						211	106		
1-5				528						178		
2-3					337						169	
2-4						380					212	97
2-5							505					222
3-4								299	54		131	
4-5								508		158		225
1-3-4									245			
1-4-5									350			
2-3-4											168	
2-4-5												283

Sensor designation

1. Synthetic-aperture SLAR.
2. Real-aperture SLAR.
3. Standard Landsat.
4. Aerial photographs.
5. Enhanced Landsat.

2.2.1 Small-Scale Study

Statistical analysis for the small-scale study was performed by analysis of variance using the GLM procedure of the SAS computer package with two levels of area and five levels of combination. The statistical model included only the two main effects. A summary of the analysis of variance is given as:

Model	R2	Area	Sensor combination
P>F		P>F	P>F
0.0001	0.997	0.0001*	0.0075*

*Significant at α=0.05 probability level.

The model, after adjustment for the mean, significantly accounts (0.0001) for the dependent variable's behavior, and accounts for 99.7 percent of variation in the dependent variable. The sensor combination effect is significant at the α=0.05 probability level.

The mean values for miles of commonality of interpreted structural elements for the sensor combinations for this test are:

1,067.5	Real-aperture SLAR and enhanced Landsat
1,040.0	Synthetic-aperture SLAR and enhanced Landsat
996.5	Synthetic and real-aperture SLAR
814.0	Real-aperture SLAR and standard Landsat
689.5	Synthetic-aperture SLAR and standard Landsat

It is seen from Duncan's multiple range test that the three combinations--real-aperture SLAR and enhanced Landsat, synthetic-aperture SLAR and enhanced Landsat, and synthetic-aperture SLAR and real-aperture SLAR--are not significantly different from each other and that the two combinations--real-aperture SLAR and standard Landsat, and synthetic-aperture SLAR and standard Landsat--are also not significantly different from each other. However, the group of three combinations together is significantly different from the group of two combinations together.

Therefore, it can be concluded from this test that the group of three combinations together, on the average, detect approximately 1.4 times more the commonality of interpreted structural elements than does the group of two combinations together, on the average.

2.2.2 Five-Sensor Overlap Area Study

Statistical analysis for the five-sensor overlap area study was performed using the Functions of Categorical responses (FUNCAT) procedure of the Statistical Analysis System (SAS) computer package. Although the FUNCAT procedure is primarily for analysis of categorical data, a procedure designed for a lower order of data on the measurement scale can be used with data from a higher order. However, there may be a loss of power and efficiency in a test when so used. However, as seen in table 5, the measurement data of the entire matrix are too sparse for analysis of variance for normally distributed data, and do not produce any separability on sensor combinations by testing of hypotheses.

Analysis for this data set was performed with 12 levels of sensor combinations and 12 levels of commonality responses. The statistical model used stated that the commonality response effects equal sensor combination effects. The resulting probability, $P>X^2$=0.0001, indicated that significant differences existed in the commonality responses among the 12 different sensor combinations.

A number of relevant hypotheses were tested. These hypotheses and the resulting probability levels are given in table 6. The results of these hypotheses tests indicate: (1) there are no significant differences among all two-level sensor combinations for commonality response at the α=0.05 probability level, and (2) there are significant differences among the three-level sensor combinations for commonality response at the α=0.05 probability level.

The total values for miles of interpreted structural elements for the two-level sensor combination of this test are:

308	Synthetic-aperture SLAR and standard Landsat
462	Synthetic-aperture SLAR and aerial photographs
534	Synthetic-aperture SLAR and enhanced Landsat
343	Real-aperture SLAR and standard Landsat
386	Real-aperture SLAR and aerial photographs
511	Real-aperture SLAR and enhanced Landsat
305	Standard Landsat and aerial photographs
514	Aerial photographs and enhanced Landsat

A Scheffé type of multiple comparison procedure (Grizzle and others, 1969, p. 498), based on the hypotheses tests of combinations, is used to investigate which sensor combinations are different from which others in the three-sensor combinations.

From table 6 it is seen that the hypotheses that the various three-level combinations are equal is rejected. The total values for miles of interpreted structural elements for the three-level sensor combinations of this test are:

573	Synthetic-aperture SLAR, aerial photographs, standard Landsat
798	Synthetic-aperture SLAR, aerial photographs, enhanced Landsat
686	Real-aperture SLAR, aerial photographs, standard Landsat
833	Real-aperture SLAR, aerial photographs, enhanced Landsat

Therefore, it can be concluded that for commonality in the two-sensor combinations in the five-sensor overlap area, there is no significant difference among the sensors. That is, that the detection differences among the sensors are due to chance alone. For commonality in the three-sensor combinations in the five-sensor overlap area, all triple combinations are significantly different from each other. That is, that they all detect different common numbers of linear miles of interpreted structural elements, in the triple and included double combinations.

Because of the disparity of results for the two-sensor combinations, for each of the small-scale study and the five-sensor overlap area study, no general conclusion regarding commonality for the length data study can be drawn. Accordingly, the study for uniqueness (to follow) must be separated into the small-scale study and the five-sensor overlap area study.

2.3 <u>Uniqueness of Contribution of Each Sensor</u>

According to Pascucci and others (1981, p. 25), the unique contribution of each sensor, or the "uniqueness" of each data set, is obtained by subtracting the total commonality length from the total length of

Table 6.--Hypotheses and probability levels of commonality responses for sensor combination effects in the five-sensor overlap area study.

Hypothesis of response designations	$P > X^2$
1=2=3=4=5=6=7=8	1.0000
9=10=11=12	0.0171*
9=10	0.0001*
9=11	0.0002*
9=12	0.0001*
10=11	0.0001*
10=12	0.0001*
11=12	0.0001*

* Significant at $\alpha = 0.05$ Probability Level

Sensor Designations

1. Synthetic-aperture SLAR
2. Real-aperture SLAR
3. Standard Landsat
4. Aerial photographs
5. Enhanced Landsat

Response Designation	Sensor Combination
1	1-3
2	1-4
3	1-5
4	2-3
5	2-4
6	2-5
7	3-4
8	4-5
9	1-3-4
10	1-4-5
11	2-3-4
12	2-4-5

interpreted structural elements for each data set. That is, (Pascussi and others, p. 33) "Total contribution of each sensor minus commonalities with other sensors equals the unique contribution of each sensor."

2.3.1 Small-Scale Study

Uniqueness for the small-scale study is developed from the total values of interpreted structural elements detected by a sensor, minus the commonality values for that same sensor. The total values are taken from the results of the experiment for total interpreted structural elements detected by length (Section 2.1.1). The results of the analysis of variance are mean values based on total detected miles of interpreted structural elements. However, certain of these sensors were found to be not significantly different at the 80-percent confidence limits. The values given in table 7A for total miles are the weighted averages for these sensors resulting from this test.

The commonality values are taken from the results of the experiment for commonality of interpreted structural elements detected by length (Section 2.2.1).

The results of the analysis of variance are mean values based on total detected miles of interpreted structural elements, defined as common to the sensors. However, certain of these sensors were found to be not significantly different at the $\alpha=0.05$ probability level. The values given in table 7A for commonality miles are the weighted averages for these sensors.

Table 7.--Uniqueness determination.

	Miles			
Sensor	Total	Commonality	Uniqueness	Percent of Total
A. Small-scale study:				
Real-aperture SLAR	2,255.5	940.4	1,315.1	58.3
Enhanced Landsat	2,255.5	1,034.7	1,220.8	54.1
Synthetic-aperture SLAR	1,944.9	940.4	1,004.5	51.6
Standard Landsat	1,634.2	751.75	882.5	54.0
B. Five-sensor overlap area study (based on two-sensor combination)				
Enhanced Landsat	1,209	420.4	788.6	65.2
Real-aperture SLAR	1,126	420.4	705.6	62.7
Aerial photographs	1,126	420.4	705.6	62.7
Synthetic-aperture SLAR	826.5	420.4	406.1	49.1
Standard Landsat	826.5	420.4	406.1	49.1

The uniqueness miles and percent of total for uniqueness for each sensor for the small-scale study are given in table 7A, and are repeated here:

Miles	Percent of total	Sensor
1,315.1	58.3	Real-aperture SLAR
1,220.8	54.1	Enhanced Landsat
1,004.5	51.6	Synthetic-aperture SLAR
882.5	54.0	Standard Landsat

2.3.2 Five-Sensor Overlap Area Study

Uniqueness for the five-sensor overlap area study is also developed from the total values of interpreted structural elements detected by a sensor, minus the commonality values for that same sensor. The total values are taken from the results of the experiment for total interpreted structural elements detected by length (Section 2.1.2). The results of the analysis utilizing the t-test, are based on total detected miles of interpreted structural elements. However, certain of these sensors were found to be not significantly different at the 80-percent confidence limits. The values given in table 7B for total miles are the weighted averages for these sensors resulting from this test.

The commonality values are taken from the results of the experiment for commonality of interpreted structural elements detected by length (Section 2.2.2). The conclusions from the FUNCAT adjustment procedure and associated hypotheses tests were that all sensors in the two-level combinations detected the same number of linear miles of common interpreted structural elements.

For the two-level combinations, the values given in table 7B for commonality miles is the weighted average values for these sensors, taken together. The uniqueness miles and percent of total for uniqueness for each sensor for the five-sensor overlap area, based on two-level combinations, are given in table 7B and are repeated here:

Miles	Percent of total	Sensor
788.6	65.2	Enhanced Landsat
705.6	62.7	Real-aperture SLAR
705.6	62.7	Aerial photographs
406.1	49.1	Synthetic-aperture SLAR
406.1	49.1	Standard Landsat

The conclusions were also that all sensors in the three-level combinations, and their included double combinations, detected different numbers of miles of common interpreted structural elements.

For the three-level combination, the situation is considerably more complicated. Accordingly, the results of the three-level combination analysis are not given.

2.4 Analysis Based on Total Interpreted Structural Elements Detected by Frequency (counts)

Analysis of frequency of interpreted structural elements was performed by using the FUNCAT procedure of the SAS computer package (Helwig and Council, 1979). The major purpose of the analysis was to determine if there was a significant difference, at some acceptable probability level, among the sensors for use in detecting frequency (that is, number of occurances) of interpreted structural elements. The null hypothesis to be tested was that the total count effect of each sensor equals the total count effect of each other sensor. The alternate hypothesis was that the total count effects are not the same. A Scheffé type of multiple comparison procedure was used to investigate which sensors were different from which others, when the total effects are found to be significant (Grizzle and others, 1969, p. 498; also refer to Goodman, 1964). A secondary purpose was to determine the relationship among the effects of area, interpreted structural elements, and (or) scale.

The data for the analysis of categorical responses are shown in tables 8 and 9. Each cell contains the frequency by count of the number of interpreted structural elements. The data were not processed using all four types of interpreted structural elements since there are too many cells with frequencies of either zero or less than five. Accordingly, the data were cumulated into suspected faults or fractures and suspected synclines/anticlines. The data were also cumulated into totals of all interpreted structural elements for a second processing. A summary of the numerical results is given in table 10. In this table, the value $P>X^2$ measures the significance probability for the total effect of the factor considered. If $P>X^2<\alpha$, the factor is deemed significant, at the α level of probability and the null hypothesis is rejected. If $P>X^2\alpha$, there is no evidence to reject the null hypothesis.

2.4.1 Small-Scale Study

Analysis of categorical responses for this data set was performed with two levels of area, four levels of sensor, and two levels of interpreted structural elements. The statistical model used stated that the area response effects equaled the interpretation and sensor effects. Because some cells still contained zero values, the quantity 0.5 was added to the values in all cells. The no scoring response function was used. The sensor effect is significant at the $\alpha=0.05$ probability level.

The total number of interpreted structural elements in this test are:

1,240	Enhanced Landsat
985	Synthetic-aperture SLAR
744	Real-aperture SLAR
461	Standard Landsat

The multiple comparison procedure indicates that at the $\alpha=0.05$ probability level, synthetic-aperture SLAR and digitally enhanced Landsat are not significantly different from each other. Real-aperture SLAR and standard Landsat are significantly different from each other and from the other two sensors.

Table 8.--Total interpreted structural elements detected by frequency-cumulated [Data from Pascucci and others, 1981 (Table VI, as modified)]

Area	Sensor	Small-scale interpreted structural elements by frequency: Probable and possible fault or fracture	Synclinal and anticlinal axis	Totals
Ugashik	Synthetic aperture SLAR	233	5	238
	Real aperture SLAR	223	0	223
	Standard Landsat MSS	76	0	76
	Enhanced Landsat MSS	317	3	320
Utukok River/ Lookout Ridge	Synthetic aperture SLAR	724	21	745
	Real aperture SLAR	476	43	519
	Standard Landsat MSS	351	30	381
	Enhanced Landsat MSS	886	32	918
Five-sensor overlap area	Synthetic aperture SLAR	366	4	370
	Real aperture SLAR	218	15	233
	Standard Landsat MSS	173	14	187
	Enhanced Landsat MSS	353	13	366
	Aerial photos	501	12	513

Table 9.--Aggregated and interpreted structural elements detected as a function of scale-cumulated [Data from Pascucci and others, 1981 (Table X, as modified)]

Sensor	Site	Scale (in 1,000's)	Large-scale interpreted structural elements by frequency: Probable and possible fault or fracture	Synclinal and anticlinal axis	Total
Synthetic aperture SLAR	Deer Creek	1:250	-	-	-
		1:100	80	1	81
		1:50	79	1	80
	Wide Bay	1:250	-	-	-
		1:100	31	1	32
		1:50	59	0	59
	Salmon River	1:25	-	-	-
		1:100	37	0	37
		1:50	105	1	106
	Mt. Peulik	1:250	-	-	-
		1:100	20	0	20
		1:50	32	0	32
Real aperture SLAR	Deer Creek	1:250	-	-	-
		1:100	31	0	31
		1:50	54	0	54
	Wide Bay	1:250	-	-	-
		1:100	21	1	22
		1:50	42	0	42
	Salmon River	1:250	-	-	-
		1:100	33	0	33
		1:50	52	0	52
	Mt. Peulik	1:250	-	-	-
		1:100	23	0	23
		1:50	26	0	26

Table 10.--Values of significance probability from analysis of categorical responses of interpreted structural elements by frequency data

Sensor	Interpreted	Scale
$P > X^2$	$P > X^2$	$P > x^2$
Small-scale study		
0.0001*	0.0066*	
Five-sensor area study		
Only one response value in data		
Large-scale study area		
0.1085o		0.0073*

* Significant at α = 0.20 probability level
o Significant at α = 0.05 probability level

The conclusion of the small-scale study is that when based on area response effects, synthetic-aperture SLAR and digitally enhanced Landsat MSS imagery together, on the average, detect significantly more interpreted structural elements than do real-aperture SLAR and standard Landsat MSS imagery.

2.4.2 Five-Sensor Overlap Area Study

Analysis for this data set was performed with five levels of sensor and one level (the totals) of interpreted structural elements. Analysis of categorical responses for this data set cannot be used since there is only one interpreted response value (the total) for each of the five sensors. Since the data are frequencies, the chi square goodness of fit test was used to determine if the differences in the data are significant. The sensor effect is significant at the α=0.05 probability level.

The total number of interpreted structural elements in this test are:

370	Synthetic-aperture SLAR
233	Real-aperture SLAR
187	Standard Landsat
513	Aerial photographs
366	Enhanced Landsat

The multiple comparisons procedure indicates that: aerial photographs are significantly different from all other sensors; at the α=0.05 probability level, synthetic aperture SLAR and digitally enhanced Landsat are not significantly different from each other; and at the α=0.05 probability level, real-aperture SLAR and standard Landsat are not significantly different from each other. These two pairs of sensors are significantly different from each other.

The conclusion of the five-sensor overlap area study is that aerial photographs, synthetic-aperature SLAR and digitally enhanced Landsat MSS imagery, each and together detect significantly more interpreted structural elements than do real-aperture SLAR and standard Landsat MSS imagery.

2.4.3 Large-Scale Study

Analysis of categorical responses for this data set was performed with four levels of area, two levels of sensor, two levels of scale, and one level (the totals) of interpreted structural elements. The statistical model used stated that the area response effects equalled the scale and sensor effects. There were no cells with missing values, and no scoring response function was used. The sensor effect is significant at the α=0.20 probability level.

The total number of interpreted structural elements in this test are:

447	Synthetic-aperture SLAR
283	Real-aperture SLAR

The conclusion of the large-scale study is that when based on area response effects, synthetic-aperature SLAR detects approximately 1.6 times more the number of interpreted structural elements than does real-aperature SLAR.

The general conclusion from the frequency data study is that at the small scales of 1:500,000 and 1:250,000, synthetic-aperture SLAR and digitally enhanced Landsat MSS imagery together, on the average, detect approximately 1.6 times more the frequency of interpreted structural elements than do real-aperture SLAR and standard Landsat MSS imagery together, on the average; and that aerial photographs at 1:80,000-scale detect approximately 1.4 times more the frequency of interpreted structural elements than do synthetic-aperture SLAR and digitally enhanced Landsat MSS imagery together, on the average. At large scales of 1:50,000, 1:100,000, and 1:250,000, synthetic-aperture SLAR detects approximately 1.6 times more the frequency of interpreted structural elements than does real-aperture SLAR.

3. DISCUSSION

The Data Analysis and Results section of this report has been directed to the major purpose of the Pascussi study--to determine the contribution of SLAR to interpreting structural elements. The secondary purpose of the study (to determine the relationship among the effects of area, interpreted structural element, and (or) scale) was not considered. The results are contained within the output of the computer analysis, and need only to be extracted and analyzed.

The contribution of SLAR is considered by Pascucci and others (1981, p. 3) as the unique, incremental contribution of SLAR compared with that from Landsat imagery and aerial photographs. Accordingly, they have measured the total length and number of interpreted structural elements that can be extracted from each of the sensors studied. They have also measured the lengths of interpreted structural elements that are in common between the paired combinations of these sensors--the commonality values. The uniqueness values (the incremental contributions) are the differences between the total values and the commonality values. That is the uniqueness values are the byproduct of the detection and analysis procedures. The quantities detected, the total values and the commonality values, must each be analyzed and the analysis results determined, before the uniqueness values can be computed. Moreover, not only the SLAR sensors have uniqueness values. Since the commonality values are only a portion of the total values, each sensor in the commonality pairs has a uniqueness value. It is these entire sets of values that have been analyzed, and the results extracted.

Uniqueness values have been computed for only the length data study, since no commonality values were obtained for the frequency data study. Within the length data study, uniqueness values have been computed for only the small-scale study and the five-sensor overlap area study. The large-scale study contained only the two SLAR sensors, so the data have no comparison with other sensors.

The small-scale study includes two sizable tracts of land in two different physiographic regions of Alaska. One of the tracts was approximately double the size of the other. The five-sensor overlap area study covered only a small portion (32 percent) of the larger area. Thus the five-sensor overlap area study is only one sample and can be considered as a lesser included portion of the small-scale study. Nevertheless, there is something different about the data from the five-sensor overlap area study, as compared to the small-scale study. This difference is indicated by the slight variance in the results of both the total length data study and the commonality length data study. In the results of the total length data study, for the small-scale study, synthetic-aperture SLAR is included together with real-aperture SLAR and enhanced Landsat, and also together with standard Landsat. For the five-sensor overlap area study, synthetic-aperture SLAR is included only with standard Landsat, and enhanced Landsat is not included with real-aperture SLAR.

In the results of the commonality data study, for the small-scale study, the three combinations of real-aperture SLAR and enhanced Landsat, synthetic-aperture SLAR and enhanced Landsat, and synthetic- and real-aperture SLAR are different from the two combinations of real-aperture SLAR and standard Landsat, and synthetic-aperture SLAR and standard Landsat. For the five-sensor overlap area study, there are no significant differences among all two-level sensor combinations. Accordingly, the uniqueness computations must be kept separate between the small-scale study and the five-sensor overlap area study.

Only the two-sensor combinations are considered for discussion and conclusion purposes.

For the two-sensor combinations leading to the uniqueness computation, the absolute values of the measures (total miles, commonality miles, uniqueness miles, and also the percent of total) are different for the sensors in both the small-scale study and the five-sensor overlap area study. However, the sense of the order of uniqueness, in miles and percent of total, are very similar. Real-aperture SLAR and enhanced Landsat are the highest in all four measures. For uniqueness and percent of total, real-aperture SLAR is highest in the small-scale study and enhanced Landsat is highest in the five-sensor overlap area study. Synthetic-aperture SLAR and standard Landsat are the lowest, and in that order, for both studies. Aerial photographs are the same as real-aperture SLAR in all four measures in the five-sensor overlap area study.

Again, since the five-sensor overlap area study is a lesser included part of the small-scale study (except for aerial photographs), it is from the small-scale study that the conclusions will be drawn.

4. CONCLUSIONS

The maximum uniqueness for detection of interpreted structural elements in Alaska is obtained from both the real-aperture SLAR sensor, and from aerial photographs; secondly from digitally enhanced Landsat MSS imagery. Both real aperture SLAR and enhanced Landsat MSS imagery sensors detected the same number of total miles of interpreted structural elements; however, real-aperture SLAR detected fewer miles in common than did enhanced Landsat. Synthetic-aperture SLAR and standard Landsat detected fewer miles than the other three sensors, and in that order, except that standard Landsat detected a higher uniqueness percent of total miles than did synthetic-aperture SLAR.

However, uniqueness is a two-sided phenomenon. Real-aperture SLAR detected a uniqueness of 58.3 percent of total compared to other sensors. Enhanced Landsat detected a uniqueness of 54.1 percent of total compared to other sensors. Each of these two sensors detected the same total miles of interpreted structural elements, and significantly more miles of interpreted structural elements than did the other sensors (except for aerial photographs). Real-aperture SLAR and enhanced Landsat each utilize a different physical phenomenon to record their imagery. Accordingly, they detect something different. This statistical analysis indicates that real-aperture SLAR and enhanced Landsat complement each other, and based on the data furnished, the use of both may lead to more complete detection of the interpreted structural elements.

5. RECOMMENDATION

As a result of this analysis using miles of linear measurement, and based upon the data furnished, it is recommneded that both real-aperture SLAR and digitally enchanged Landsat MSS imagery be utilized together in Alaska to assure the likelihood of obtaining the maximum detection of interpreted structural elements.

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