SECTION 37

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# THE STATUS OF PARAMETRIC STUDIES IN RADAR AGRICULTURE

by

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A brief overview of geoscience tasks under NASA Contract NAS9-10261 is given, followed by a report on the status of parametric studies for radar agricultural determinations. The overview will outline this year's progress on 1) an information system for agriculture based on the use of remote sensor data by county agents; and 2) the design, testing and implementation of interpretation keys for agriculture.

The task of crop identification from radar imagery is a complex problem involving the intersecting geometries of two "real worlds:" that of SLAR design parameters and that of biotic parameters. Through appropriate design strategy we are able to conduct a series of semi-controlled experiments on combinations of radar variables to evaluate their influence on radar return from crops. To illustrate the approach, approximate $\sigma^o$ values for sorghum are presented for two frequencies each having two polarizations and a range of viewing angles. Analyses are underway to simultaneously evaluate all parameters measurable from the imagery for each crop type and growth stage. Our greatest needs at present are 1) to expand the data base in both the frequency and angular domains; 2) to improve quality control in the signal-to-image-to-digitizer transformations; and 3) to speed up data extraction from computer maps.

## INTRODUCTION

Radar agricultural studies at the University of Kansas are being conducted by geographers, consequently the interest is aimed more at spatial information (the introduction and diffusion of phenomena into an agricultural scene) than to other types of agricultural information. With this in mind we will present a scenario of how we view the role of radar in an agricultural monitoring program. For a more complete statement of our overall program goals and progress, see Morain (1972). All of the work in this report is funded under Contract NAS9-10261.

## IMAGE INTERPRETATION

Our research approach is directed along two lines: the development of interpretation strategies using radar imagery; and, the evaluation of signal/terrain interactions to aid in crop identification. These lines of effort are complimentary to one another though not mutually dependent. Among the most important aspects of the interpretation approach is our recommended strategy for information extraction and dissemination and our studies into the use and development of radar dichotomous keys.

## The Information System

Figure 1 is a first approximation of an information system designed solely for agriculture. It is an "information system" in the strictest sense of the word rather than a data acquisition system. In the presentation of Figure 1 data are returned from some form of agricultural satellite to a data return facility from which it can be disseminated to counties as needed. Our strategy really begins with what happens at the county level. We envision the capability for automatic data processing of both image and digital data and that automated dicotomous keys will be among the available algorithms. Since the county agents are most familiar with their own particular area (of the number of acres in production, the local weather conditions for crop production, the nature of local diseases, etc.), they should be in the best position to accurately and closely interpret data returns from remote sensors. In addition they are in a position to very quickly disseminate information at the local information user's level. Such users are indicated in the diagram.

From the initial interpretation and acquisition of information at the county level, the diagram shows a flow upward through the agricultural hierarchy through state and regional offices to the national and international scene. At the state and regional level, data from counties can be aggregated and put into a broadened frame of reference. At these levels we find a somewhat different user group, with different information needs, so what was earlier considered "information" at the county level reverts to data for the region. Finally, at the highest levels in the agricultural hierarchy, we can see still another user group with different needs than the previous group. This information can be created by further aggregation and reprocessing results from lower levels. The diagram in Figure 1 is really no different from the agricultural system as it now exists, but it represents a change of thinking for remote sensing. To the author's knowledge other so-called "information systems" have assumed a beginning point at the top and disseminate information downward. Clearly this is not the most efficient strategy if information needs are tied to higher frequency data acquisition. To illustrate the concept of a county agricultural interpretation center, Figure 2a, showing an artist conception of ADP hardware, has been extracted from the work of Lorsch (1969). Figure 2b is essentially the same idea but shows what might evolve at the Regional Data Center.

Figures 3a and 3b represent the pattern of idle land as it might appear in the year 1980. These drawings are modified from an article by Mayer and Heady (1969) and are included here to suggest the possible economic-geographic uses of agricultural information extracted from a future remote sensing system. Figure 3a shows the pattern of idle land based on acreage quotas. One can see that the distribution of idle land is fairly well distributed throughout the country and that no particularly large areas are idled from agricultural production. Figure 3b, however, shows the pattern of idle land based on a free market economy. In this case we see that the distribution of idle land has shifted significantly and that the spring wheat belt in the Dakotas, as well as much of the agricultural land of the South, are taken out of production. Presumably, under the acreage quota system these two areas can compete in the market place, but under a free market economy they cannot successfully compete.

These kinds of trends could, and we think eventually will, be monitored by remote sensing systems. They will serve a function not only in telling us where the major areas of idle land may reside but they may also be useful in guiding our decision making process regarding the kind of policies we want in the agricultural community. In each part of the country the appearance and characteristics of idle land will change and it would be very difficult, indeed, for a system based on the dissemination of information from the top downward to ever monitor idle land. If, on the other hand, we work from the county level upward, we can be rest assured that the county agent knows what attributes to look for in identifying idle land and these data can then be aggregated at regional and national levels into the kinds of maps represented in Figure 3.

## Dichotomous Keys

To aid in the implementation of the information system described above we are pursuing a number of interpretation strategies to aid the county agents in information extraction. Amongst the most useful of the strategies so far investigated is the dichotomous key. These were reported last year at the 3rd annual review. In the meantime we have prepared keys for Ka-band, X-band, and Ku-band radar imagery, for both natural and cultural vegetation categories. When reported last year we had just begun to automate one of the Ka-band keys from the Westinghouse 1965 overflight of Garden City. At that time we were achieving on the order of 50% correct idenfication of crops using a set of Yes/No decisions based on human interpretation of the imagery. Since our preliminary trials, we have improved the keys as well as our ability to make and automate them, to the extent that we can now correctly identify between 75 and 80% of the cropped fields at Ka-band in September. We are confident that we can push this level even higher but we are reaching an impass because agricultural data come in county size blocks.

In order for us to really test the utility of these keys, and of this approach, we are nowin critical need of radar imagery for the whole of Finney County and at specified times of the year so that we can compare our results with those of the county agriculturalists and the state statistician. From the standpoint of the information system,keys are potentially extremely useful because they can be created by county agents, who, as we have already indicated, know the situation in their county very well. We hope to have a final report out on the use and implementation of dichotomous keys by June, 1972. In this report we will include the general algorithm for automating keys on IDECS-like hardware. In the algorithm now in use, keys for specific identification problems are inserted as subroutines. In this way subroutines based on any type of imagery, any time of the year, or for the identification of particular terrain conditions, can be inserted for rapid analysis. Figure 4 is an example of the October 1969 X-band key which illustrates the concept of keys for agricultural landscapes. Figure 5 is a "matrix" key for the identification of forest types at Yellowstone. In the forthcoming report on keys we discuss the relative merits of each of these approaches and the degree to which they can be successfully automated.

## PARAMETRIC STUDIES

Under the radar agricultural subtasks of NAS9-10261 we are engaged in a number of studies aimed at evaluating signal/terrain interactions for agricultural scenes. A brief review of these studies was given at the 3rd annual review a year ago and need not be repeated here. Progress on these experiments has either been reported, or will be reported shortly, in the form of technical reports. Rather than outline all of the material here it would be more useful to summarize our progress on parametric studies.

## Background

Almost all of the radar parametric studies to date have been conducted using one of three or four frequencies: the Westinghouse Ka-band imagery from 1965; the NASA Ku-band imagery flown at various times in 1969, 70 and 71; and X-band imagery flown by Michigan in 1969 and 1971. In all of these frequencies, for the entire range of look angles represented and polarizations obtained, we can extract image densities for every crop type and state at Garden City. What we are attempting to do in N-dimensional space is isolate those particular combinations of frequency, polarization, look angle and time which give us the best discrimination of particular crop types or crop states. This strategy is diagramed in Figure 6 on which is shown only three parameters: frequency, look angle and polarization. Intuitively, given two nearly identical crops such as corn and sorghum, one would expect that somewhere in this data space corn and sorghum could not be discriminated. In another sector, however, these two crops may be partially identifiable and in yet another part, the two may be entirely distinguishable. We are looking for those areas where crops can be identified. It does not mean that, should we find such combinations, all crops will be identifiable with that combination of parameters, merely those under particular scrutiny. This reasoning argues strongly in favor of polyfrequency radar so that we can acquire a full compliment of frequencies look angles, and times in the growing season. Under the present array of data available to us, as shown in Figure 7, it is clear that we cannot achieve our goal without a more complete data set. Working with single frequencies is exactly the same as working with an extremely narrow band filter, and we cannot even be sure that the frequencies available are the optimum "filters" for viewing the kinds of terrains we want to view. For all we know, we may be looking at agricultural landscapes through the equivalent of a blue filter.

## Image-based Studies

All of the available imagery from the systems described above, with the exception of the Michigan X-band data, have been digitized by Optronics at a 50 micron cell size. From these data we are extracting means, standard deviations, and other measures for each field in the agricultural scene. Dr. Haralick has been working with the same digitized data in his pursuit of image texture. Progress on that work is reported in the next paper.

Initially we began these studies using only the high quality fields as described by our field teams. In order to increase the data set, however, we more recently began using all of the information for each crop type, irrespective of the crop quality. We know this injects terrain "noise" into our results, but there seems to be little alternative.

Results. - To illustrate the kind of results we are getting, Figure 8 represents a 3-dimensional plot for sorghum in July. We have plotted the image density against viewing angle and frequency, using the Ka and Ku-band systems. The results seem to indicate that for these two frequencies there is no particular best viewing angle where image density variations are minimized. The addition of other image parameters might improve the situation as regards this particular crop and certainly such N-dimensional approaches should be pursued. At the present time we are engaged in similar kinds of investigations for other crop types using this 3-dimensional model in hopes that when one crop is overlayed on another we will see the extent to which their data spaces overlap. Space does not permit even a beginning to a discussion of this topic. For further information the interested reader is referred to Morain, 1972.

## Non-Image Based Studies

The only system presently available to us that is capable of obtaining backscatter values across a range of frequencies is the polypanchromatic system developed at the University of Kansas. This system operates in the 4-8 GHz region over a range of viewing angles from nadir out to $70^{\circ}$. As part of the initial tests of this system last summer, the geography group was engaged in two separate studies. The first focused on backscatter returns from soils under different conditions and the second focused on returns from corn.

Soil Studies.- Previous soil studies together with observations from the imagery suggest there is almost certainly a moisture/roughness trade-off in backscatter from soils. That is to say, a dry/rough surface may give exactly the same return as a moist/smooth surface. In our use of the polypan system, therefore, we rototilled a small field near the Center for Research to 3 broad roughness classes (roughness here characterized in terms of micro-relief rather than in soil texture). After obtaining backscattering cross sections from these three different roughness categories in their dry state (about 15% moisture by volume) we wetted the fields by hand to bring their moisture content up to near field-capacity (about 30% moisture by volume). Thus we had three different roughness categories and two moisture conditions for which we obtained data.

Results: In Figure 9 we have plotted the backscattering cross sections from a few spot frequencies within the 4-8 GHz range at selected viewing angles. The results clearly illustrate the tendency for returns to "string out" at any given frequency and look angle. There is no suggestion in the diagram that any one frequency or look angle is best for discriminating these soil conditions. On the other hand we must remember that not all of the data have been plotted and that there may be other frequencies and look angles in the 4-8 region where the data might cluster. It might, in fact, be possible, using these more or less continuous data, to create a mean trend surface for each of the six soil conditions to see whether or not they are discriminable.

Corn Studies.- The corn experiment was aimed precisely at evaluating the contribution of moisture in crop backscatter. At the time microwave data were taken, field members took measurements of soil moisture and temperature. Stratified plant samples were collected and later processed for their moisture content. We have partitioned the moisture measurements into two categories: 1-foot whole plant increments; and stalk, leaf, and cob increments.

Results: We have not finished our analysis of these moisture data. However, there is a preliminary suggestion (which needs further evaluation) that at particular frequencies and look angles moisture in corn is highly detectable. The implications of this are exciting and far reaching. The diagram in Figure 10 represents the backscattering coefficients from corn looking diagonally across the rows for the same set of frequencies and look angles as presented in Figure 9. We see the same kind of stringing out in the returns, except that in the case of corn there seem to be some frequencies and look angles where the data cluster rather nicely. Whether or not these frequencies and look angles would be useful as identifiers for corn remains to be seen. We need to carry out similar studies with related crops such as sorghum and with grossly different crops such as soy bean or sugar beet. Our experiments this coming summer will, in fact, be along these lines.

## CONCLUDING REMARKS

In general the radar agriculture work can be divided into two broad sectors: The development of interpretation strategies for imagery, in which our emphasis so far has been on dichotomous keys; and the search for frequency, angular and other microwave dependencies of crops for use in discrimination. These two sectors are not mutually exclusive because many of the ideas generated from the parametric studies can, and are, being used in the development of interpretation strategies. In assessing our overall progress we seem to be making more headway in the area of interpretation strategies than in the parametric studies. We hope in the upcoming growing season to divorce ourselves a little more from the Garden City test strip and begin to obtain data on a county wide basis. This is critical because agricultural data come in county-size units. Unless we get information on this scale there will be no basis for comparing our results with those obtained by standard USDA techniques. So far we have had one flight over the whole of Finney county in June of 1971 (NASA 16-5 system). We have produced a mosaic from that imagery (Figure 11) and we will be able to use it for preliminary studies of acres in wheat and total acres in production. The mosaic will provide us a temporal base-point which will be useful in monitoring the spread of such phenomena as circular irrigation, the spread of crops such as sugar beets, and many other phenomena. In closing I might also point out that only by obtaining imagery on a county wide basis and comparing our results with traditional techniques will we be able to cost evaluate the ability of radar as an agricultural remote sensor.

## REFERENCES

1. Lorsch, Harold G., 1969, "Agricultural Resources Information Systems - The Users Point of View", American Astronautical Society, 15th Annual Meeting, Denver, Colorado.

2. Mayer, L. V. and E. O. Heady, 1969, "Projected State and Regional Resource Requirements for Agriculture in the United States in 1980", Iowa Agriculture and Home Economics Experiment Station, Iowa State University of Science and Technology, Research Bulletin 568.

3. Morain, S. A., (ed.), 1972, "Radar Applications in Agriculture/Forestry Annual Report on Subtasks 2.5.2 and 2.5.3 of NASA Contract NAS9-10261."

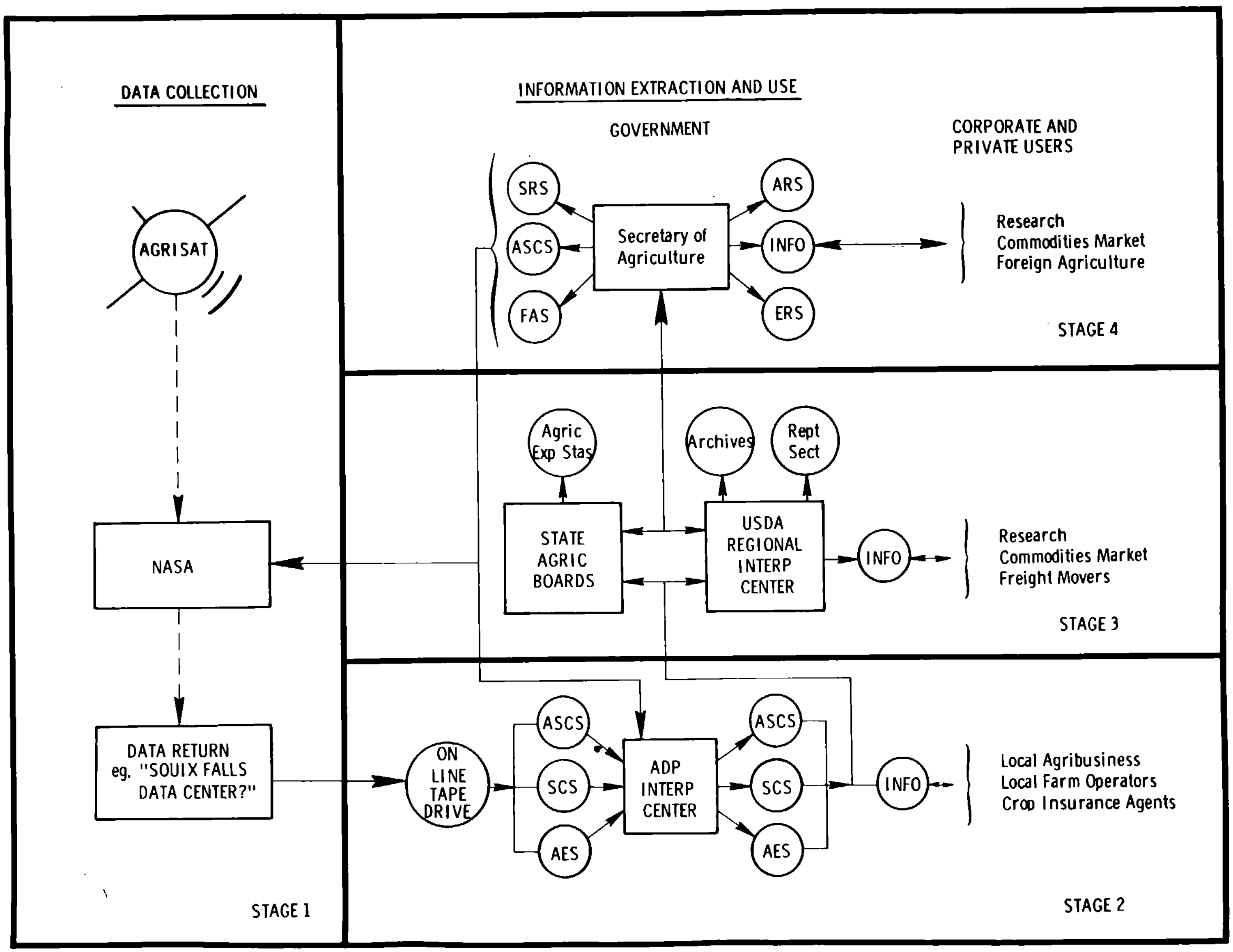
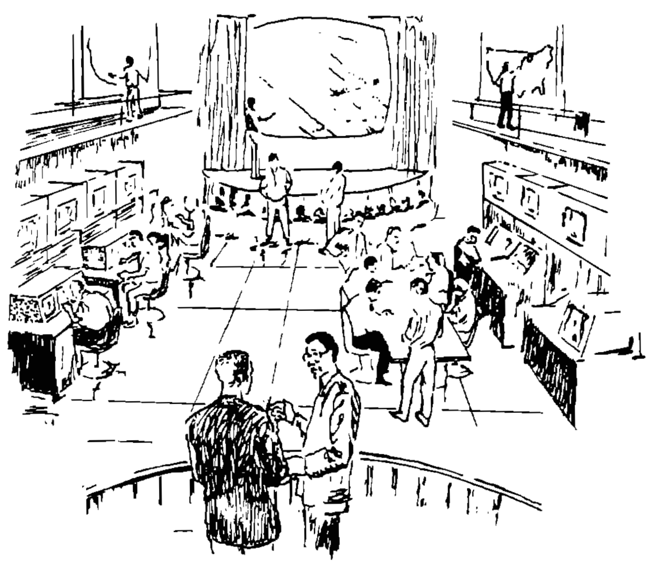

DATA COLLECTION
AGRISAT
NASA
DATA RETURN
eg. "SOUIX FALLS
DATA CENTER?"
STAGE 1
INFORMATION EXTRACTION AND USE
GOVERNMENT
CORPORATE AND
PRIVATE USERS
SRS
ASCS
FAS
Secretary of
Agriculture
ARS
INFO
ERS
Research
Commodities Market
Foreign Agriculture
STAGE 4
Agric
Exp Stas
Archives
Rept
Sect
STATE
AGRIC
BOARDS
USDA
REGIONAL
INTERP
CENTER
INFO
Research
Commodities Market
Freight Movers
STAGE 3
ON
LINE
TAPE
DRIVE
ASCS
SCS
AES
ADP
INTERP
CENTER
ASCS
SCS
AES
INFO
Local Agribusiness
Local Farm Operators
Crop Insurance Agents
STAGE 2

FIGURE 1.


a.

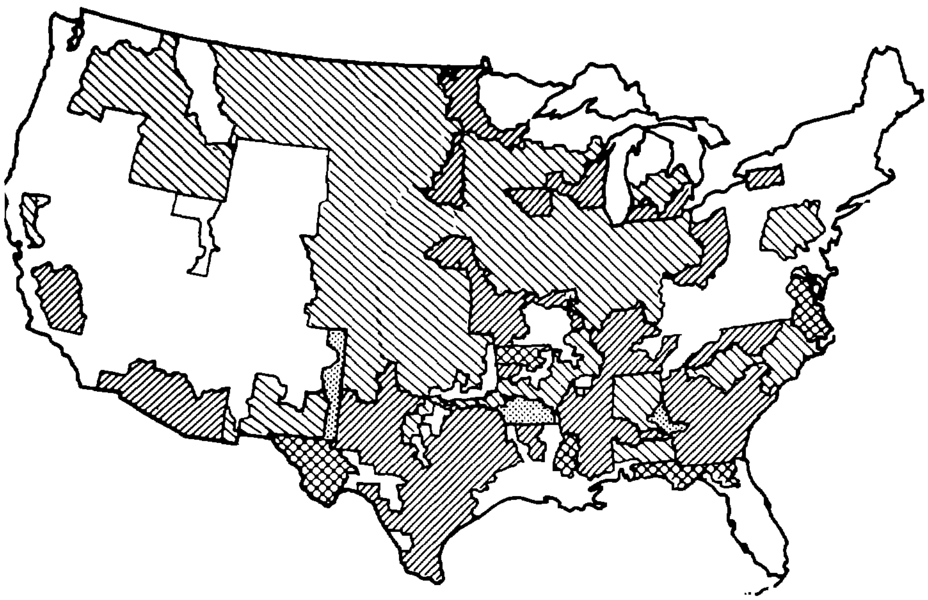


b.

Data Processing Facilities in Agriculture
a) The County Agent's Office; b) The Regional Office.
(After Lorsch, 1968)

FIGURE 2.

C.4.



a. PROPORTION OF TOTAL CROPLAND UNUSED FOR MAJOR CROPS IN EACH OF THE 144 CROP PRODUCING REGIONS UNDER AN ACREAGE QUOTA PROGRAM WITH TREND LEVEL EXPORTS IN 1980.

b. PROPORTION OF TOTAL CROPLAND UNUSED FOR CROPS IN EACH OF THE 144 PRODUCING REGIONS UNDER A FREE MARKET WITHOUT COTTON QUOTAS AND WITH TREND LEVEL EXPORTS IN 1980.

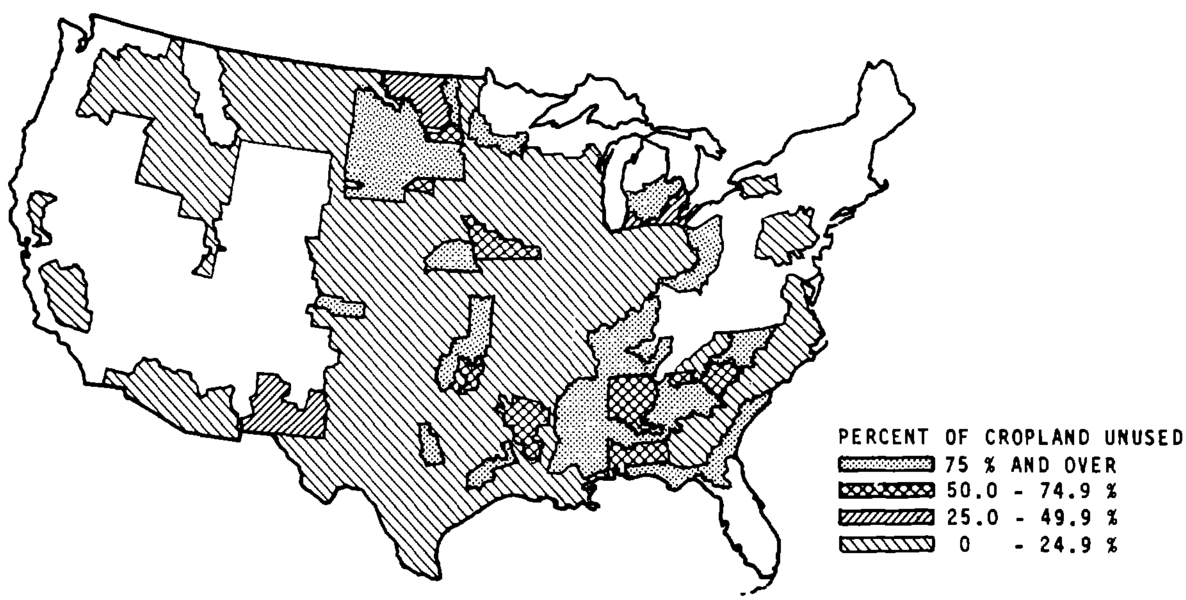



FIGURE 3.

# FIGURE 4.

PROBABILITY* KEY FOR CROP TYPES AT GARDEN CITY, KANSAS

for

OCTOBER

(Derived from Radar Imagery)

A. Field has a moderately high to high return (light grey to white on radar positive) (with respect to HH)
- B. Field has a homogeneous** tone (with reference to HH)
  - C. Field displays a shift in tone from HH (lighter) to HV (darker)
    - D. Amount of tone shift is relatively unpronounced
      - E. HV tone is homogeneous ----------------------------- sugar beets; or wheat > 3"
        - EE. HV tone is not homogeneous---------------------- fallow
    - DD. Amount of tone shift is relatively pronounced
  - CC. Field does not display a tone shift HH (lighter) to HV (darker)
    - F. Field displays a tone shift from HH (darker) to HV (lighter)
      - G. Field has evident lineations--------------------------- cut alfalfa
      - GG. Field does not have evident lineations
    - FF. Fields does not display a tone shift from HH (darker) to HV (lighter)
- BB. Field does not have a homogeneous tone

AA. Field does not have a moderately high to high return
- H. Field has medium low to moderate return (medium dark to medium light on radar positive)
  - I. Field has a homogeneous tone (with reference to HH)
    - J. Field has lineations parallel to long axis of field
      - K. Tone shift is evident from HH (dark) to HV (light) -------maturing alfalfa (flood irrigated)
      - KK. Tone shift is not evident
    - JJ. Field does not have lineations
      - L. Field displays medium coarse texture (particularly on HV image)----grain sorghum (rows ⊥ flight line)
      - LL. Field has no obvious image "texture"
        - M. Field has a moderate tone shift (HH to HV)--------alfalfa > 12"
        - MM. Field has an unpronounced tone shift------------wheat > 3"
  - II. Field does not have a homogeneous tone
    - N. Cultivation pattern is observable (particularly on HV image)---emergent wheat
    - NN. Cultivation pattern is not observable
      - O. Boundary shadowing is observable---------------------mature corn
      - OO. Boundary shadowing is not observable
- HH. Field does not have moderately low to moderately high return
  - P. Field has very low return (very dark grey to nearly black on radar positive)
    - Q. Field has a homogeneous appearance-----------------------recently tilled
    - QQ. Field does not have a homogeneous appearance
  - PP. Field does not have very low return

*This key is experimental. It is based on only one look-direction (and for a narrow range of incidence angles) for one flight during October 1969 - almost at the end of the growing season for that year. It is a probability key in the sense that only the most likely, economically important crops are indicated for any given spot in the listing. To use it the interpreter must make a series of yes/no decisions until a logical end point is reached. For example, the first decision relates to image tone: does the field have a high or moderately high return (A) or does it not have such a return (AA)? If the answer is AA, then for subsequent decisions, that portion of the key above AA can be ignored, and the interpreter's attention focused on material listed below AA. The second decision would then be whether or not the field had a medium low or moderate return (HV vs. HH in the key). The process continues in this fashion until no further choices can be made. Notice that, if the location PP is reached, an error in judgment has been made. When this happens the entire process must be repeated. Similar reasoning applies to points BB, DD, GG, FF, KK, OO, and QQ, though future revisions of the key may provide information at these locations.

**"Homogeneous" refers to the uniformity of return intensity within the boundaries of a given field, i.e., there is no evident mottling of tone.

VERBAL KEY TO THE VEGETATION OF
YELLOWSTONE NATIONAL PARK

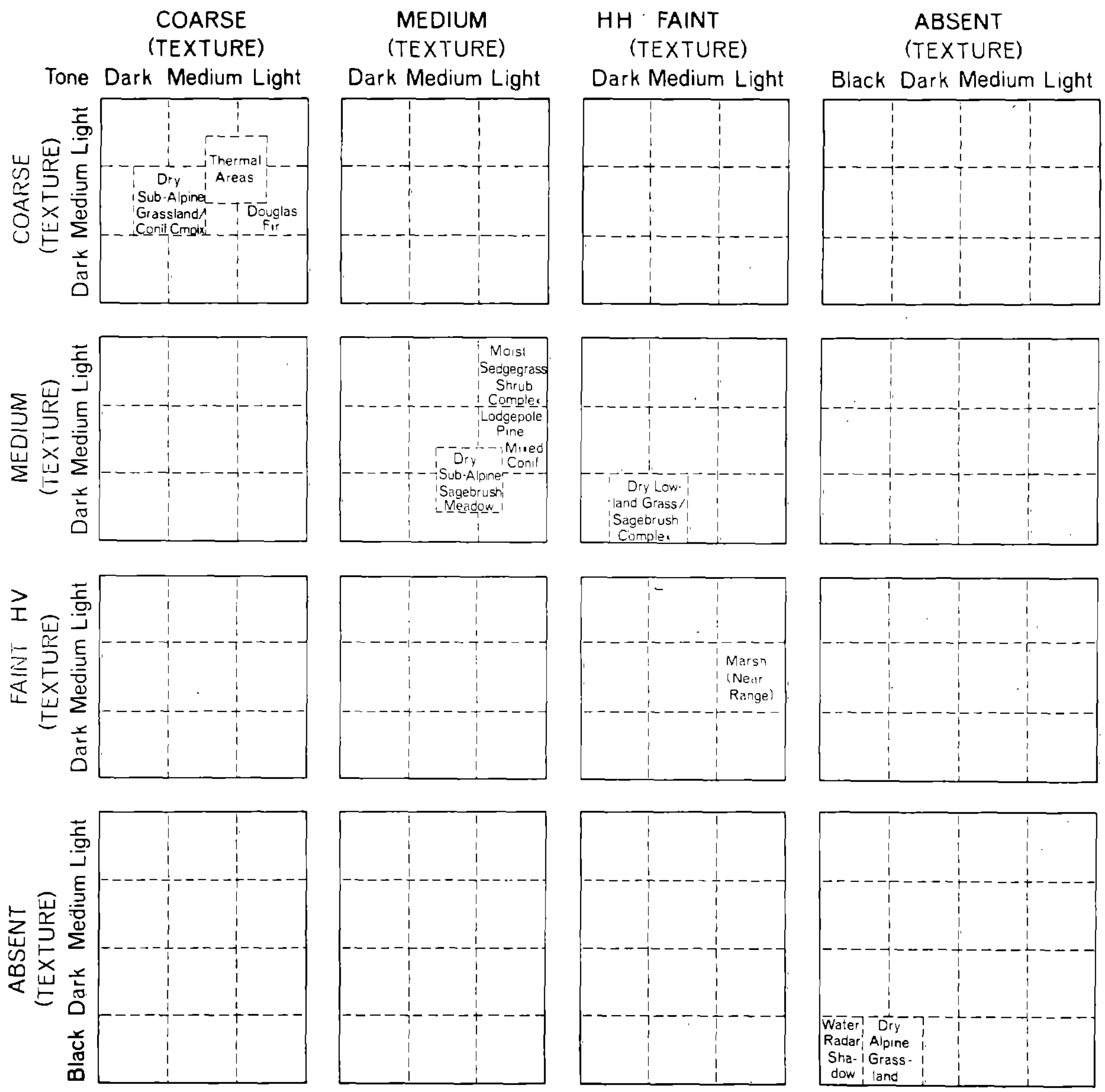
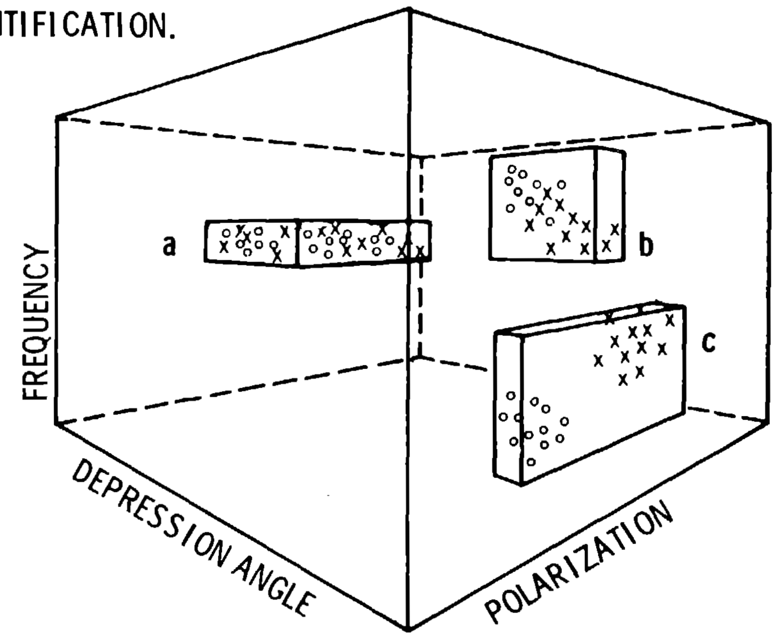
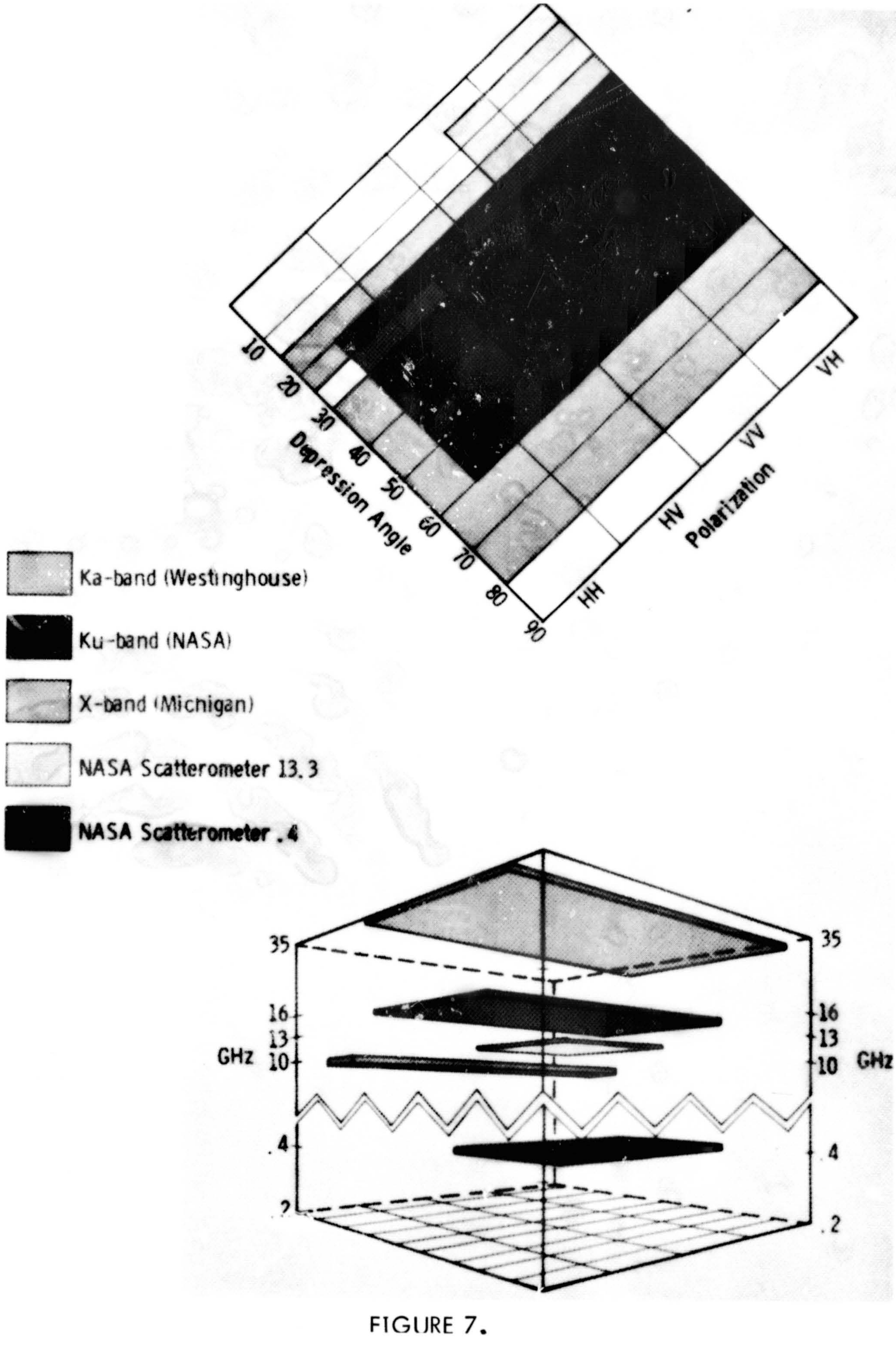



Figure 5 . Verbal matrix key to the various vegetation communities which were developed from radar imagery. This key allows ready comparison of HH and HV radar polarizations.

FIGURE 6

**DATA CELLS IN SYSTEM DESIGN SPACE SHOWS NEED FOR WIDE SWATH, POLY FREQUENCY DEVICE FOR MAKING AGRICULTURAL IDENTIFICATION.**





10
20
30
40
50
60
70
80
90
Depression Angle
HH
HV
VV
VH
Polarization
Ka-band (Westinghouse)
Ku-band (NASA)
X-band (Michigan)
NASA Scatterometer 13.3
NASA Scatterometer .4
35
16
13
10
GHz
.4
.2


FIGURE 7.

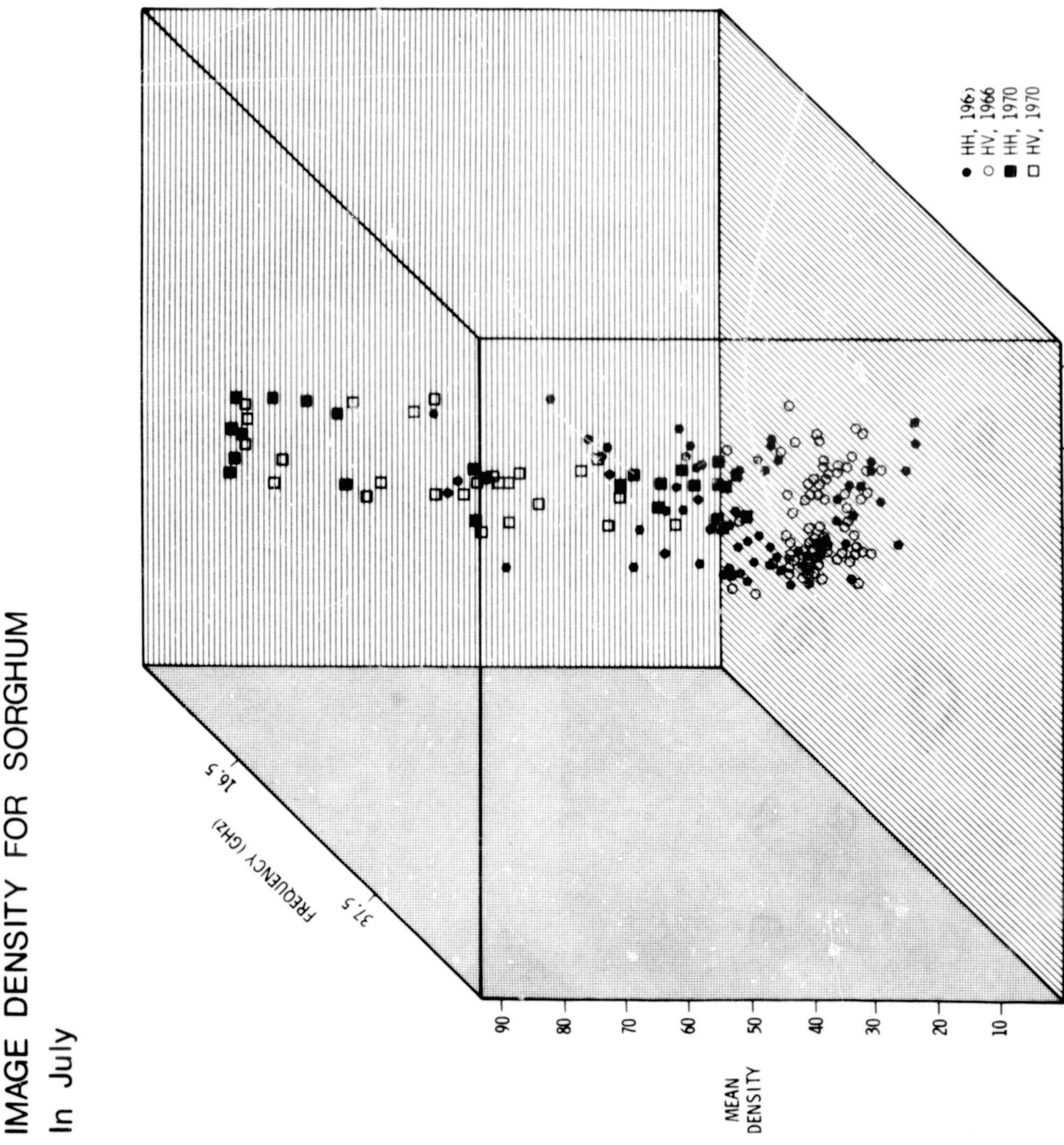


IMAGE DENSITY FOR SORGHUM
In July
MEAN
DENSITY
90
80
70
60
50
40
30
20
10
FREQUENCY (GHZ)
16.5
37.5
5
10
15
20
25
30
35
40
LOOK ANGLE
● HH, 1966
○ HV, 1966
■ HH, 1970
□ HV, 1970

FIGURE 8.

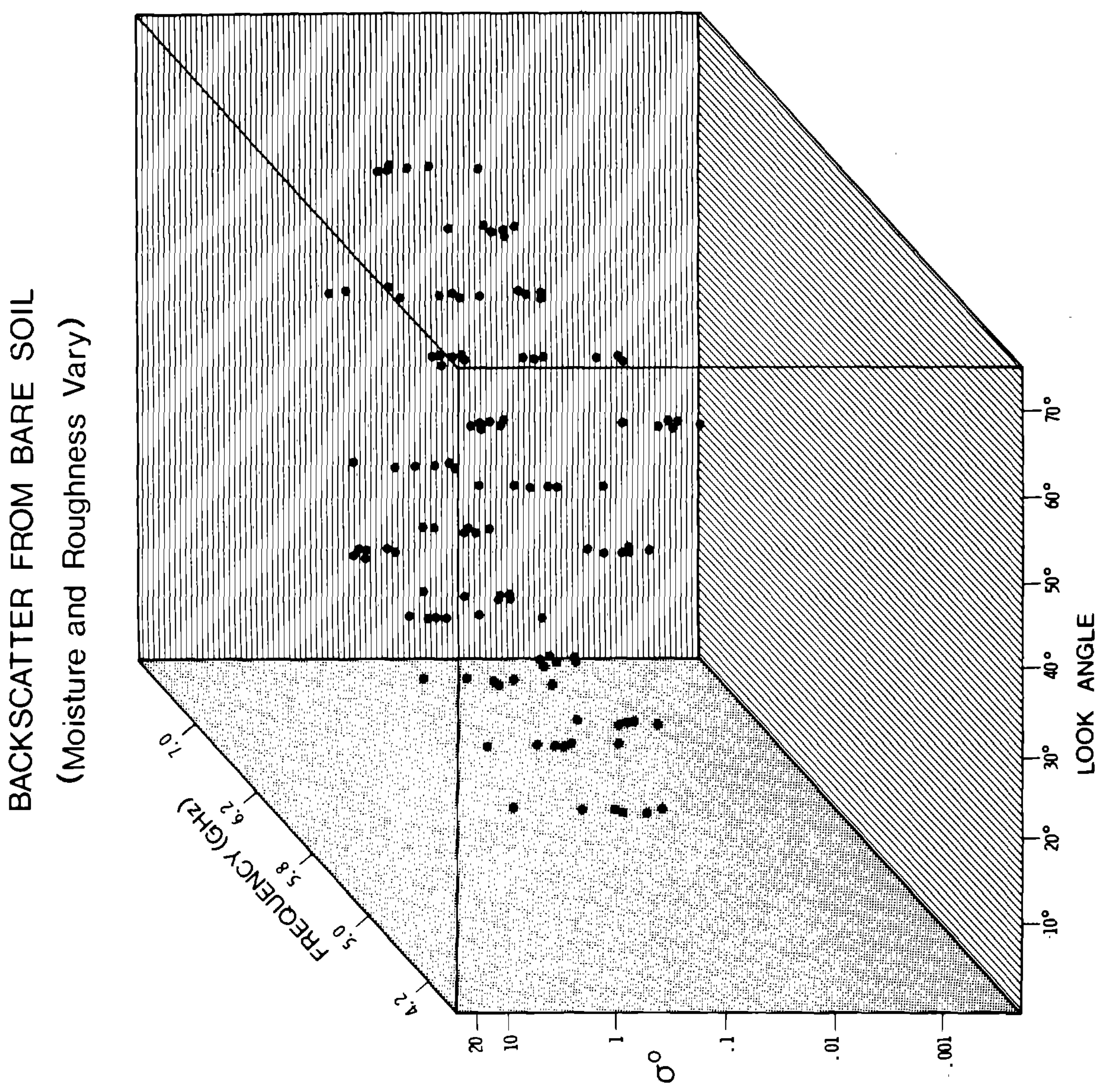

BACKSCATTER FROM BARE SOIL
(Moisture and Roughness Vary)
FREQUENCY (GHz)
4.2
5.0
5.8
6.2
7.0
LOOK ANGLE
10°
20°
30°
40°
50°
60°
70°
σ°
20
10
1
.1
.01
.001

FIGURE 9.

BACKSCATTER FROM CORN
(Look Direction Diagonal to Row Direction)

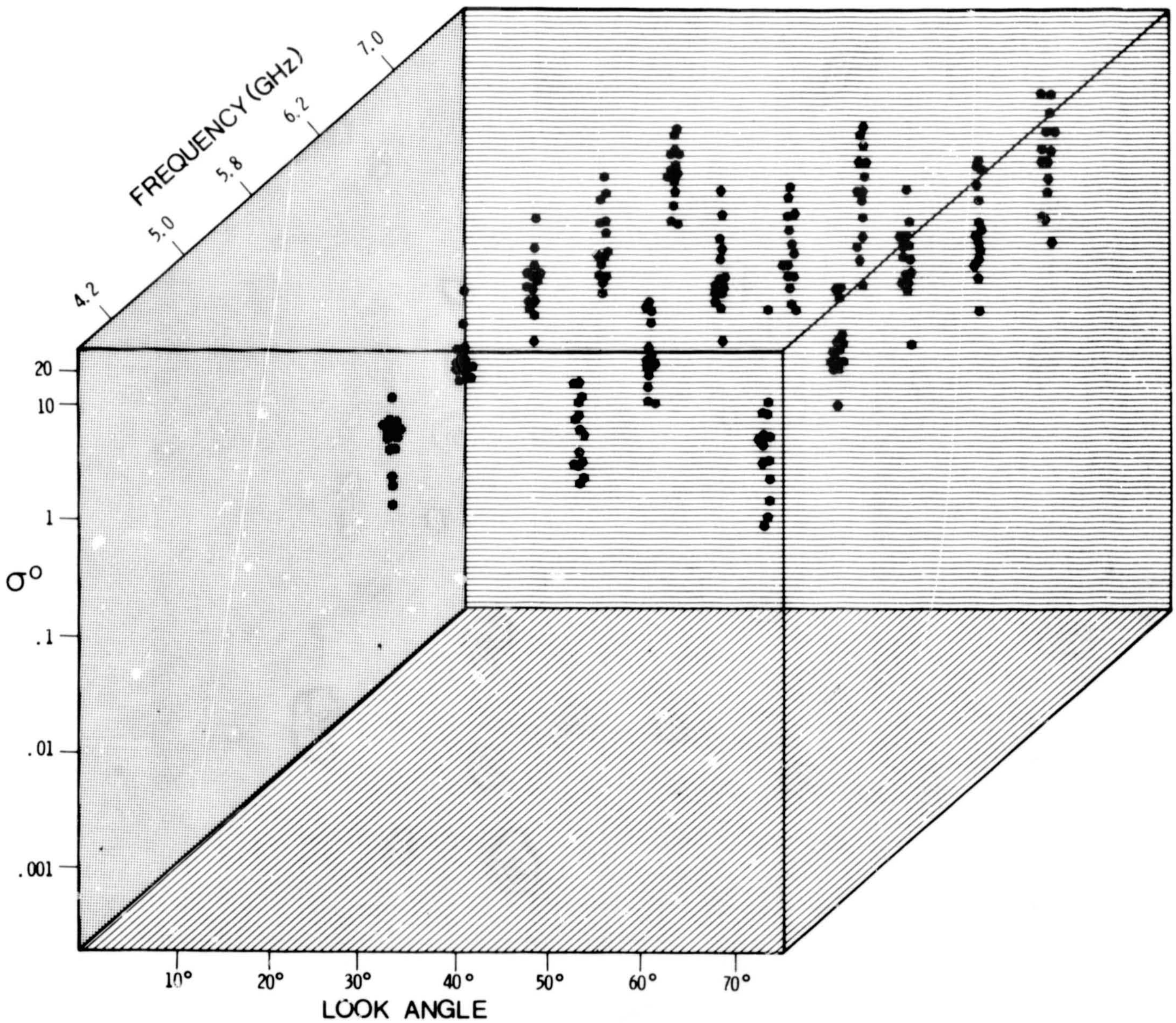



FIGURE 10.

FINNEY COUNTY, KANSAS
JUNE, 1971
NASA DPD-2 SIDE-LOOKING AIRBORNE RADAR

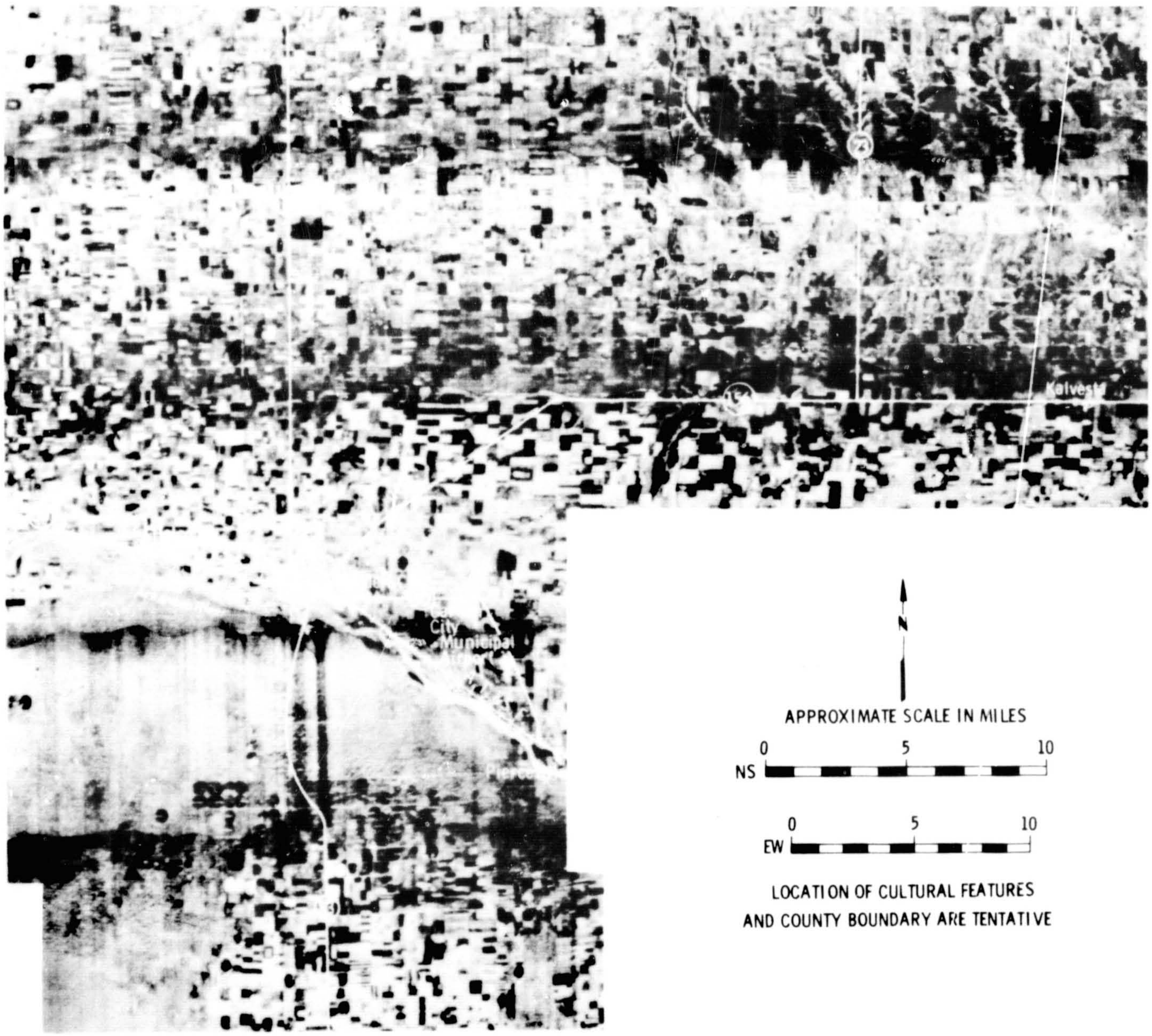



FIGURE 11.