Return To: Larry Biehl

JSC - 09797

LANDSAT - D THEMATIC MAPPER TECHNICAL WORKING GROUP

FINAL REPORT

National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER
Houston, Texas
JUNE 1975

COMPILED BY:

WARREN HOVIS
JIM NICHOLS
ANDREW POTTER
FRED THOMSON

EDITED BY:

JAY HARNAGE
DAVID LANDGREBE

TABLE OF CONTENTS

APPENDICES

1
INTRODUCTION

This report describes the results of the LANDSAT-D Thematic Mapper Technical Working Group Meeting held at Purdue University on April 30, May 1 and 2, 1975. The Thematic Mapper is a second generation earth resources scanner having significantly advanced characteristics over that of the current and exceptionally successful MSS (Multispectral Scanner) used in the LANDSAT series. This new instrument is planned for spacecraft launch in 1980.

Several previous meetings, plus a significant amount of research, have been useful in delineating preliminary performance specifications for the Thematic Mapper. The purpose of this meeting was to make final technical recommendations on these specifications prior to the final design and development phase of the flight hardware being undertaken by NASA. A group of 40 scientists and engineers from government, industry and the universities were invited. Selection of the invitees was based upon experience and specific expertise in sensor system design, data processing (preprocessing and information extraction), and various earth resources disciplines. Organization and membership of the group is contained in Appendix C.

The tone and thrust of the meeting was established by Mr. William E. Stoney, Director, Earth Observation Programs in his opening remarks. These remarks are contained in their entirety in Appendix A.

The group was charged to provide and substantiate recommendations for the Thematic Mapper specifications based on:

a. The detailed Mission Objectives (See Appendix B)

b. Performance criteria (the classification accuracy of a machine data analysis system when utilized in vegetative mapping tasks)

c. Instrument and System related constraints (See Appendix D)

During the meeting, briefings were given to provide the participants with further background detail, after which deliberations were conducted by four sub-groups. A more detailed scenario of the meeting organization is presented in Appendix C.

The resulting recommendations, and the program elements deemed in need of further research are presented in Section 2 of this report. These recommendations were synthesized from four individual subgroup reports on the final day of the meeting. They were documented into this form by the editors and reviewed by the Consolidation Panel for correctness.

The recommendations made are based both upon specific documented results, which are referenced in the subgroup reports, and upon the combined engineering judgements of the group members. These judgements are the results of knowledge derived from many references and years of research. Section 3 contains an edited bibliography of such research results.

2

RECOMMENDATIONS AND CONCLUSIONS

The Thematic Mapper Technical Working Group has concluded the following:

A. Instrument and Orbit Parameters

1. Spectral Bands

The recommended spectral bands are located in those areas of the spectrum where maximum discrimination of vegetation type and condition can be expected. The bands have been narrowed to take advantage of such important features as the chlorophyll absorption region of green vegetation.

For a given application, fewer than six bands have been shown to be sufficient for maximum classification accuracy; but the same three or four bands will not be optimum for any given time, place, or specific application. Therefore, it is critical that as many regions of the spectrum as possible be included. Seven spectral bands have been recommended, as follows:

Band	Value/Comments
0.45-0.52μm	1. Land use mapping, Soil/vegetation differences, deciduous/coniferous differentiation. 2. While this band's greatest value is perhaps in hydrological studies, it is believed to have value for vegetative studies as well. However, if a seven band system is not feasible, this band should be the first considered for deletion.
0.52-0.60	1. Important indicator of green reflectance for assessment of growth stage and vegetation vigor. 2. Desirable to keep this band as narrow as possible around the green peak without unduly sacrificing signal.
0.63-0.69	1. Chlorophyll absorption for species differentiation. 2. Lower end of band can be shifted

	to 0.61 if sensor design dictates; upper end is critical and should not be shifted.
0.74-0.80	1. Sensitive vegetation studies, including biomass and stress. 2. Keep band as narrow as possible around the vegetation reflectance shoulder.
.80-0.91	1. High vegetative reflectance, species identification and water body delineation. 2. 0.91μm is critical and should be the upper limit to avoid water absorption band.
1.55-1.75	1. Vegetation moisture conditions; snow/cloud differentiation. 2. This band width should be maintained to avoid the water absorption band.
10.4-12.5	1. Temperature variations and characteristics; vegetation density and cover-type identification. 2. The lower end of the band is critical to avoid the ozone absorption band; upper limit fixed to avoid the carbon dioxide absorption band.

2. Sensitivity

$NE\Delta\rho$ of 0.005 @ 13% reflectance for total system in all visible/NIR bands for range of reflectances associated with vegetation problems.

$NE\Delta T$ of 0.5 K @ 300°K for total system, including atmospheric attenuation.

There is evidence that improved radiometric resolution is as important as spectral resolution in applications requiring more difficult discrimination and where numerical models are to be applied.

3. Spatial Resolution

30-40 meters, with spectral and radiometric resolution having higher priority. To accomodate working with the large percentage of agriculture plots of 20 acres and less, the design goal should be a 30 meter IFOV. Appropriate trade-offs can be made to maintain the spectral and radiometric requirements, recognizing that IFOV should not be treated lightly in a "whatever results" manner.

4. Dynamic Range

The general recommendation was that the design philosophy used in LANDSAT proved to be a wise choice and should be used in the Thematic Mapper to the extent possible. Reflecting this philosophy, specifications for each band are as follows:

Band	Surface Reflectance for Saturation
0.45-0.52	20%
0.52-0.60	58%
0.63-0.69	53%
0.74-0.80	75%
0.80-0.91	75%
1.55-1.75	50%
10.4-12.5	270-330 K

5. Geometric Accuracy

Registration of pixels between scenes to within 0.5 pixel (rms) after ground processing, is required. This level of accuracy is needed to achieve the classification accuracies required by the user when the data is processed in the multitemporal mode.

6. Temporal Resolution

A 9-day repeat cycle, using 2 satellites, was recommended. Obtaining 9-day repeat with 2 sensors on the same satellite is not desirable for the following reasons:

a. The atmospheric variabilities will be increased with the larger cant angles.

b. The terrain effect on geometric error will be increased. In the nadir scan system (single scanner) the terrain error will vary from 0 at nadir to 15 meters error at the swath edge for a 100 meter difference in terrain elevation. In the offset scan system (2 scanners) the terrain error will vary across the swath from 15 meters to 30 meters for a 100 meter difference in terrain elevation.

7. Scanning Method

Rectilinear scanning is preferred over conical scanning for the following reasons:

a. Conical scanning would make direct read-out capability more compliplicated and probably considerably more expensive.

b. The conical scan provides a constant atmospheric path, but it views the terrain at varying scan angles and aspect with respect to crop rows and other regular terrain patterns introducing data variances that are not well understood.

c. Terrain effects on geometric accruacy are less on the average for the rectilinear scanning method, since in this case for a portion of each scan the system is looking at or near nadir.

All group members were in agreement that the data should be delivered in rectilinear form.

8. Thermal Band Resolution

Thermal data at the same spatial resolution as the other bands would be ideal, but the panel members accepted resolution of 120-meter for this band because of system design constraints. It is recommended that this band's resolution be an odd multiple, e.g. 3X or 5X, of the other bands. This will provide for convenient registering or centering the thermal band on the other bands in performing classification and overlaying the image.

9. Atmospheric Effects

Since the atmospheric effect is not an instrument parameter, an attempt was made to consider such effects only as they relate to other sensor parameters. Specific comments on atmospheric effects are found in the individual subgroup reports.

B. Areas for Further Study

1. The group was not convinced that a spatial sampling rate of 1.4 IFOV (along scan line) is appropriate or necessary.

Since the sampling scheme will obviously have an effect on the data rate and ground station throughput considerations, the group recommends further study to optimize the sampling scheme for the total system, which includes data acquisition and processing.

2. It is apparent that there has been no coordinated program to collect, analyze and interpret the spectral data on a multidisciplinary basis to optimize channel selection for future satellites. Therefore, it is recommended that such a coordinated program be undertaken as soon as possible so that the results may have a significant impact on the shuttle era scanner systems and proposed aircraft multispectral scanner systems.

3. It is recommended that cloud cover build up during the day be studied carefully for the agricultural areas of high interest to determine the optimum time for data acquisition. Optimum time for thermal data acquisition must be considered in conjunction with the cloud cover.

4. The LANDSAT operational system should be thoroughly integrated with the needs of central data processing, regional data centers, and small low-cost data centers to provide maximum efficiency and economy in utilization by state, regional, and foreign users. Rapid turn-around requirements need to be established and assessed.

5. For a given classification task, errors arise in classification due to statistical variability in the scene (including the atmosphere) and statistical variability occuring in the sensor system and data stream. Examples of the latter are detector noise and quantitization error. Errors are also introduced due to the finite IFOV. Studies should be conducted to assess quantitatively the relative sensitivity of classifier performance to these system parameters, and to define methods to compensate for them.

6. It was observed during the meeting that although a large dynamic range is necessary in the data system to handle data gathered at various sun angles, the entire range may not be necessary for any given sun angle. Thus an on-board gain or digitization changing scheme may be useful in reducing the number of bits which must be transmitted, without sacrificing data quality. The feasibility of this possibility should be investigated.

3

BIBLIOGRAPHY

Following is a list of scientific papers which provide the background knowledge against which the engineering judgements represented in the recommendations of Section 2 were made. (Specific references are given in the subgroup reports, Appendices E-H). The list is grouped to correspond to the subsections of Section 2 which are

A. Spectral Band Selection
B. Sensitivity
C. Spatial Resolution
D. Dynamic Range
E. Geometric Accuracy
F. Temporal Resolution
G. Scanning Method
H. Atmospheric Effects
I. General

Spectral Band Selection

1. Laboratory for Agricultural Remote Sensing (LARS). 1967-1970.
Remote Multispectral Sensing in Agriculture.
Annual Report Volumes 1, 2, 3, and 4, Research Bulletins 831, 832, 844, and 873. Purdue University Agricultural Experiment Station. West Lafayette, IN 47906.

2. Fu, K. S., D. A. Landgrebe and T. L. Phillips. 1969.
Information Processing of Remotely Sensed Agricultural Data
Proceedings of the IEEE, Volume 57, Number 4, pp 639-653.

3. Hoffer, R. M. and C. J. Johannsen. 1969.
Ecological Potentials in Spectral Signature Analysis
Chapter 1: Remote Sensing in Ecology, Edited by R. L. Johnson
University of Georgia Press, Athens, Georgia, pp 1-16 and
LARS Information Note 011069.

4. Allen, W. A., H. W. Gausman, and C. L. Wiegand. 1970.
Spectral Reflectance from Plant Canopies and Optimum Spectral Channels in the Near Infrared
3rd Annual Earth Resources Program Review, NASA MSC, Volume III, Section 23, pp. 1-15.

5. Sinclair, T. R., R. M. Hoffer, and M. M. Schreiber. 1971.
Reflectance and Internal Structure of Leaves from Several Crops During a Growing Season
Agronomy Journal, Volume 63, Number 6, pp 864-868 and LARS Information Note 122571.

6. Wacker, A. G. 1972.
Minimum Distance Approach to Classification
Ph.D. Thesis, Purdue University, West Lafayette, IN 47906 and LARS Information Note 100771.

7. Coggeshall, M. E. and R. M. Hoffer. 1973.
Basic Forest Cover Mapping Using Digitized Remote Sensor Data and ADP Techniques
MS.Thesis, Purdue University, West Lafayette, IN 47906 and LARS Information Note 030573.

8. Gausman, H. W., D. E. Escobar, and R. R. Rodriquez. 1973.
Discriminating Among Plant Nutrient Deficiencies with Reflectance Measurements
Proceedings of the 4th Biennial Workshop on Aerial Color Photography in the Plant Sciences, University of Maine, Orono, Maine, July 10-12, 1973, pp 13-27.

9. Richardson, A. J., M. R. Gautreaux, and C. L. Wiegand. 1973.
24 Channel MSS CCT Land Use Classification Results
Machine Processing of Remotely Sensed Data Symposium, Purdue University, October, 1973, pp 2A-33 to 2A-53.

10. NASA Lyndon B. Johnson Space Center. 1973.
Corn Blight Watch Final Report
NASA Earth Resources Program, Johnson Space Center, Volumes I-III, Houston, Texas, June 1973.

11. Coggeshall, M. E., R. M. Hoffer, and J. S. Berkebile. 1973
A Comparison Between Digitized Color Infrared Photography and Multispectral Scanner Data Using ADP Techniques.
Proceedings of the 4th Biennial Workshop on Aerial Color Photography in the Plant Sciences, University of Maine, Orono, Maine, July 10-12, 1973, pp 43-56, and LARS Information Note 033174.

12. Gausman, H. W. and W. G. Hart. 1974.
Reflectance of Sooty Mold Fungus on Citrus Leaves Over the 2.5 to 40 μm Wavelength Interval
Journal of Economic Entomology, Volume 67, pp 479-480.

13. Kumar, R. and L. F. Silva. 1974.
Statistical Separability of Spectral Classes of Blighted Corn
Remote Sensing of Environment 3, pp 109-115 (1974) and LARS Information Note 041774.

14. Kumar, R. and L. F. Silva. 1974.
Statistical Separability of Agricultural Cover Types in Subsets of One Through Twelve Spectral Channels
Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Environmental Institute of Michigan, April 15-19, 1974, Ann Arbor, Michigan, and LARS Information Note 041974.

15. Biehl, L. L. and L. F. Silva. 1974.
A Multilevel, Multispectral Data Set Analysis in the Visible and Infrared Wavelength Regions.
Proceedings of the IEEE, Volume 63, Number 1, January 1975, and LARS Information Note 082174.

16. Biehl, L. L. and L. F. Silva. 1974.
Machine Aided Multispectral Analysis Utilizing Skylab Thermal Data for Land Use Mapping
Machine Processing of Remotely Sensed Data Symposium, Purdue University, June 1975, and LARS Information Note 052775.

Sensitivity

17. Hughes, G. F. 1968.
On the Mean Accuracy on Statistical Pattern Recognizers
IEEE Transactions on Information Theory, January 1968.

Spatial Resolution

18. Kan, E. P. and D. L. Ball. 1974.
Data Resolution Versus Forestry Classification
Machine Processing of Remotely Sensed Data Symposium, Purdue University, and JSC Report 09478.

19. NASA Lyndon B. Johnson Space Center. 1975.
Crop Identification Technology Assessment for Remote Sensing (CITARS) Final Report, Volumes 1-10, Houston, Texas 77058.

Dynamic Range

20. Laboratory for Agricultural Remote Sensing. 1968.
Remote Multispectral Sensing in Agriculture, Volume 3, (See 1.)

21. Holmes, R. A. and R. B. MacDonald. 1969.
The Physical Basis of System Design for Remote Sensing in Agriculture.
Proceedings of the IEEE, Volume 57, Number 4, pp 629-639.

22. Hoffer, R. M. and C. J. Johannsen. 1969.
Ecological Potentials in Spectral Signature Analysis
(See 3)

23. Sinclair, T. R., R. M. Hoffer, and M. M. Schreiber. 1971.
Reflectance and Internal Structure of Leaves from Several
Crops During the Growing Season (See 5)

Geometric Accuracy

24. Anuta, P. E. 1969.
Digital Registration of Multispectral Video Imagery
Society of PhotoOptical Instrumentation Engineers, Volume 7,
Number 6.

25. Anuta, P. E. 1970.
Spatial Registration of Multispectral and Multitemporal
Digital Imagery Using Fast Fourier Transform
Techniques
IEEE Transactions on Geoscience Electronics, Volume GE-8, Number 4,
pp 353-368, and LARS Information Note 052270.

26. Krathy, Valadimnn. 1972.
Photogrametric Solution for Precision Processing of ERTS Images
Proceedings of the 12th International Congress of Photogrammetry,
Ottawa, Canada, July 1972.

27. Lillestrand, R. L. 1972.
Techniques for Change Detection.
IEEE Transactions on Computers, Volume C-21, Number 7. July 1972.

28. Colvocorresses, A. P. and R. B. McEwen. 1973.
EROS Cartographic Process
NASA Symposium on Significant Results Obtained from ERTS-1
March 5-9, 1973.

29. Derocichie, W. F. and R. B. Forrest. 1974.
Potential Positioning Accuracy of ERTS-1 MSS Images
American Society of Photogrammetry Meeting, St. Louis, Missouri,
March 10-15, 1974.

30. Schoonmaker, J. W. 1974.
Geometric Evaluation of MSS Images from ERTS-1
American Scoiety of Photogrammetry Meeting, St. Louis, Missouri,
March 10-15, 1974, pp 582-588.

31. Colvocorresses, A. P. 1974.
The Map Projection of the ERTS-1 Multispectral Scanner
American Society of Photogrammetry Meeting, St. Louis, Missouri,
March 10-15, 1974.

32. Wong, K. W. 1975
Geometric and Cartographic Accuracy ERTS-1 Imagery
Photogrammetric Engineering, Volume 41, Number 5, May 1975,
pp 621-635.

Temporal Resolution

33. Steiner, D. 1970.
Time Dimension for Crop Surveys from Space
Photogrammetric Engineering, Volume 36, February, 1970, pp 187-194.

34. Lillestrand, R. L. 1972.
Techniques for Change Detection
(See 27)

35. Gausman, H. W., W. A. Allen, R. Cardenas, and A. J. Richardson. 1973.
Reflectance Discrimination of Cotton and Corn at Four Growth Stages
Agronomy Journal, Volume 64, pp 194-198.

36. Wray, J. R. 1973.
Remote Sensing of Land-Use Changes in U.S. Metropolital Regions: Techniques of Analysis and Opportunities for Application
Third Earth Resources Technology Satellite-1 Symposium, Washington, D. C., December 10-12, 1973, pp 339-340.

37. Moons, H. D. and A. F. Gregory. 1973.
A Study of the Temporal Changes Recorded by ERTS and Their Geological Significance
Third Earth Resources Technology Satellite-1 Symposium, Washington, D. C., pp 845-850.

38. Blair, Byron. 1974.
Interpretation of Temporal Data from ERTS-1, Demonstrating the Brown and Green Wave.
Proceedings of the First International Congress of Ecology, The Hague, September 1974, pp 283-285.

39. Ebert, D. H. et al. 1973.
Conical Scan Impact Study, Volume 1, General Central Data Processing Facility
Final Report, Bendix Aerospace Systems Division, NASA Contract NAS5-21903, September 1973.

Atmospheric Effects

40. Kriegler, F., W. Manila, R. Nalepka, and W. Richardson. 1969.
Preprocessing Transformations and Their Effects on Multispectral Recognition
Sixth Symposium on Remote Sensing of the Environment, Ann Arbor Michigan, October 1969.

41. Pitts, D. E., W. E. McAllum, A. E. Dillinger. 1974.
Effects of Atmospheric Water Vapor on Automatic Classification of ERTS Data
Ninth International Symposium on Remote Sensing of Environment, April 15-19, 1974, Ann Arbor, Michigan.

42. Turner, R. E., et al. 1974.
Influence of the Atmosphere on Remotely Sensed Data
Proceedings of the 18th Annual Technical Meeting of
Society of Photo-optical Engineers, Scanners and Imagery
Systems for Earth Observations, San Diego, California,
August 1974.

GENERAL

43. Laboratory for Agricultural Remote Sensing. 1967.
Remote Multispectral Sensing in Agriculture, Volumes 1 and 2.
(See 1)

44. Holmes, R. A. and R. B. MacDonald. 1969.
The Physical Basis of System Design for Remote Sensing
(See 21)

45. Cardenas, R., H. W. Gausman, W. A. Allen, and Marcia Schupp. 1969-70.
Remote Sensing of Environment, Volume 1, pp 199-202.

46. Fu, K. S., D. A. Landgrebe, and T. L. Phillips. 1969.
Information Processing of Remotely Sensed Agricultural Data
(See 2)

47. Wolfe, W. 1970.
Handbook of Military Infrared Technology
Office of Naval Research, p. 228.

48. NASA Manned Spacecraft Center. 1970.
Third Annual Earth Resources Program Review, Houston, Texas.

49. Rody, W., C. Olsen. 1971.
Estimating Foliar Moisture Content from Infrared Reflectance Data
Third Biannual Workshop for Color Aerial Photography in Plant Sciences, March 1971.

50. NASA Manned Spacecraft Center. 1972.
Fourth Annual Earth Resources Program Review, Volumes 1-4,
January 17-21, 1972. Report MSC-05937, Houston, Texas.

51. National Aeronautics and Space Administration. 1972.
Advanced Scanners and Imaging Systems for Earth Observations,
Cocoa Beach, Florida, December 11-15, 1972. Report SP 335.

52. Goddard Space Flight Center. 1973.
NASA/EOS Payload Discussion Group Final Report
EOS-410-09, October 1973.

53. NASA Lyndon B. Johnson Space Center. 1973.
Corn Blight Watch Final Report
(See 10)

54. Thomson, F. J., J. D. Erickson, R. F. Nalepka, and J. D. Weber. 1974.
Multispectral Scanner Data Applications Evaluation, Volumes 1 and 2
NASA/JSC 09251 and ERIM Report 102800-40-F, December 1974.

55. NASA Lyndon B. Johnson Space Center. 1975.
CITARS Final Report, Volumes I-IV
(See 19)

56. Wiegand, C. L., H. W. Gausman, J. A. Cuellar, A. H. Gerberman, and A. J. Richarson. 1974.
Vegetation Density as Deduced from ERTS-1 MSS Response
Proceedings of the 3rd ERTS-1 Symposium, Volume 1, Section A
NASA SP-351, pp 93-116..

57. Cheeseman, C. E., et al. 1975.
Total Earth Resources System for the Shuttle Era, Final Reports
Volumes 1, 2, 3, and 5. General Electric Company, Valley Forge, Pennsylvania, March 1975.

58. Gausman, H. W., A. H. Gerbermann, and C. L. Wiegand. 1975.
Use of ERTS-1 Data to Detect Chlorotic Grain Sorghum
Photogrametric Engineering, Volume XLI, pp 177-181.

59. Wiegand, D. L., H. W. Gausman, and W. A. Allen.
Physiological Factors and Optical Parameters as Bases of Vegetation Discrimination and Stress Analysis
Proceedings, Seminar on Operational Remote Sensing, American Society of Photogrammetry, Falls Church, Virginia, pp 82-102.

APPENDIX A

OPENING REMARKS BY MR. WILLIAM E. STONEY

APPENDIX A

Opening Remarks by Mr. William Stoney

ERTS (LANDSAT) has been an incredibly successful system - physically (it's on it's way toward it's 3rd birthday), and scientifically (it has been effectively the sole source of all the data returned from space directly measuring phenomena related to the inventorying and management of earth's resources). The second satellite (LANDSAT-2) has recently been launched and NASA has a firm commitment to launch a third (LANDSAT-C) in 1977. The user community, at the federal, state and local levels is showing an ever increasing appetite for the LANDSAT data, and an increasingly sophisticated understanding of the uses to which it can be put. They have, in fact, moved more rapidly into the use of digital data than we had really planned.

We are now gathered here to define the second earth resources instrument (noting that the modest additions we are making on the MSS for LANDSAT-C are really that - modest). The process of defining this second generation instrument has been going on for several years, as many of you know, since you have been involved. We think our studies and our research programs have arrived at the point where we know in general terms what the state of instrument and spacecraft technology will allow us to build in the time span left us before our desired 1980 flight date. We also believe from our experience with the user community that the major applications which need and will use LANDSAT data all depend to a greater, or lesser, degree on the ability of the instrument to classify vegetation (i.e., world crop production - range and forestry management - land use classification and watershed management).

Therefore, as we have very carefully called out in your letter of invitation, we are seeking your guidance on a fairly restricted set of questions. We do, however, want any comments you may have about the "larger" program options which are also mentioned in the letter. The question really comes down to this:

Given: (1) We wish to focus our remote sensing capability on a set of uses which have a common need to identify vegetative cover, making use of automatic data analysis techniques.

(2) We have developed (or are developing) an instrument capability - which, while significantly greater than the MSS, is limited

to a finite aperture due to cost, size, weight engineering and satellite integration problems.

To Find: The proper allocation of measurement capabilities; number of channels, location and bandwidth - effective signal to noise ratio, and IFOV.

There is one more thing I must emphasize. We want your advice because we believe you are the most knowledgeable, experienced people we can find to answer these questions. But we also want to know <u>why</u> you are giving the answer you give, particularly what experimental evidence do we have for making the tradeoffs. If the evidence is sparse, or non-existent, we would like that pointed out also.

Just keep in mind one thing. We are about to ask a very cost-conscious government to spend twenty or thirty million dollars to develop a new instrument. We must have the kind of knowledge that allows us to say that if we produce these capabilities our measurement capability and therefore the value of our information will be well worth the cost of our efforts. Note that this is quite a different way of looking at a new instrument than we have been accustomed to in past programs where the promise of new, and hopefully, better information for research was sufficient justification. In a real sense, the thematic mapper must be looked upon as first an operationally useful tool, and second, a research instrument.

APPENDIX B

LANDSAT-D MISSION OBJECTIVES AND PARAMETERS

APPENDIX B

LANDSAT-D MISSION OBJECTIVES AND PARAMETERS

Primary Mission Objectives - L. Walter

General

I. Monitor world-wide food productivity - for balance of trade, world food bank commitments

II. Survey local productivity - for improved local agriculture management.

III. Map Agriculture land use - for improved planning and productivity.

IV. Monitor range lands - for improved livestock management.

V. Survey forest resources.

VI. Watershed and water use management.

VII. Land use change detection

Specific

I. Forecasting Major Crop Commodity Abundances

Allocation of resources (fuel, fertilizer, capital investment)

Management of storage/transportation facilities

Detection of areas impacted by food deficiency

Management of import/export

Major Crops

Calories	Protein	World Trade
Wheat		Wheat
Rice		Soybeans
Corn	Soybeans	Corn
Barley		Cotton
Potatoes		

II. Survey Local Crop Productivity

- .Scheduling and distribution of fertilization
- .Optimization of planting dates
- .Management of irrigation practices
- .Detection and control of disease and insect infestations

III. Map Agricultural Land Use

- .Survey of Arable land
- .Optimization of Crop-type fitness
- .Plan long-term investments
- .Monitor climatically-induced changes

IV. Monitor Rangeland

- .Forecasts of range condition
- .Determination of local grazing load
- .Monitor climatically - induced range condition changes

V. Survey Forest Resources

- .Inventory
- .Control of infestation and blight

Mission Requirements Drivers - L. Walter

(LANDSAT-I Baseline)

Improved Spatial Resolution

- .Management of local crop practices
- .Early detection of disease/insect infestation
- .Improved mensuration

Improved Classification Accuracy

- .Identification of crop type
- .Detection of stress
- .Determination of planting/harvesting readiness

Increased Temporal Resolution

- .Effective Scheduling of Planting, Harvesting, Fertilization

- .Timely Warning of shortfall/surplus
- .Efficient control of disease/insect infestation

LANDSAT-D Mission Parameters - J. Harnage

Orbit		
.Altitude	-	705 Km (380nm)
.Inclination	-	99° Sun-synchronous
.Descending node time	-	1100 Hrs (nominal)
Coverage		
.Area	-	Near global (± 81° latitude) land and near coastal waters
.Repeatability	-	Initially: 17-18 days Goal: 7-9 days

APPENDIX C

MEETING ORGANIZATION AND GROUP MEMBERSHIP

APPENDIX C

Meeting Organization and Working Group Membership

The meeting was organized by a committee composed of the following members.

David Landgrebe, Working Group Chairman
Professor of Electrical Engineering
Director of LARS
1220 Potter Drive
Purdue University
West Lafayette, Indiana 47906 (317/749-2052)

Richard Moke, Working Group Co-Chairman
Earth Resources Program Office
Code HC
NASA/Johnson Space Center
Houston, Texas 77058 (713/483-3666)

Louis Walter, Working Group Co-Chairman
EOS-A Project Scientist
Goddard Space Flight Center Code 920.0
Greenbelt, Maryland 20771 (301/982-4671)

M. Jay Harnage, Jr., Working Group Co-Chairman
Earth Resources Program Office, Code HC
NASA/Johnson Space Center
Houston, Texas 77058 (713/483-6357)

Ruth Whitman
Code ER
NASA Headquarters
Washington, D.C. 20546 (202/755-8584)

It was the responsibility of this group to propose members for the working group, devise the meeting agenda, and the manner of conduct of the working group business.

Members were selected for the working group based upon their special expertise and experience. A complete list of those participating including their affiliation, education, and a brief statement of their experience is given at the end of this appendix. Care was exercised that experts regarding not only sensor systems, but also data processing and the various earth resources disciplines would be present in appropriate proportions in the working group. Figure C-1 shows the distribution with regard to these fields of expertise. This figure also shows the distribution of affiliations, with regard to government, industry, and university.

EOS Thematic Mapper Technical Meeting

Matrix of Participants

	Speciality			
Affiliation Type	Sensor	Data Processing	Earth Surface Discipline	Row Totals
Government	Hovis Potter Steiner	Billingsley	Salomonson Wiegand Wigton Ungar	8
Industry	Koso Laverty Lowe Norwood	Bernstein Cheeseman Ebert Erickson Thomson Viglione	Castruccio Draeger	12
University	Holmes Rouse	Haralick Nichols Swain	Bauer Blair Hoffer Morain Shay Simonett	11
Column Totals	9	10	12	31

RESOURCE PERSONS:

Jaffe, Legault, Stoney, and Weinstein.

Note: Names underlined indicate members of the Consolidation Panel

Figure C-1

The format of the meeting is displayed on Figure C-2, which gives the meeting agenda. The morning of the first day was utilized in providing needed background information to the working group. Items covered included the specific objectives of the meeting (see Appendices A and D), the purpose of the EOS Mission (see Appendix B), a review of fundamentals involved in selection of system parameters, a discussion of the currently proposed Thematic Mapper System Parameters, and a review of a study done by the Environmental Research Institute of Michigan, regarding this system (see Final Report, Multispectral Data Applications Evaluation, Environmental Research Institute of Michigan, Report No. 102800-40-F, NASA/JSC Report 09241 December, 1974).

Each member of the working group was requested to submit a statement of 1000 words or less, prior to the meeting, regarding his viewpoint in selecting Thematic Mapper Parameters. These position papers were synthesized by three group members, one with sensor system background, one from data processing, and one from the earth surface cover and user disciplines. Each of these members provided a review of the position papers, and in this way, in a short period of time, the major issues within the position papers were placed before the entire working group.

The major work of the meeting was conducted after dividing the participants into four subgroups. Each subgroup contained members from each of the three columns of Figure 1, thus insuring experts in the various aspects of the system were present in the subgroups. The subgroup membership is indicated in Figure C-3.

Conclusions and consensus were arrived at on the third day of the meeting, based on presentations by the leaders of each of the four subgroups. The fact that there was relatively little diversity in recommendations from the four essentially identically constituted subgroups suggests that the best possible solution to the question before the working group was reached.

The final report of the working group was the responsibility of the consolidation panel whose membership is indicated in figure C-1 and C-3.

A list of resource persons present at the meeting are contained on the following page. This is followed by the resumes of the working group participants.

Agenda

EOS Thematic Mapper Working Group

April 30, May 1-2, 1975

	Time	Subject	Speaker	Duration
Wed	9:00 A.M.	Welcome, Agenda, Introductions, Mechanics	Landgrebe	45 min
	9:45	Charge to the Working Group	Stoney	15 min
	10:00	EOS Mission Objective	Walter	20 min
	10:20	EOS Description and Profile	Harnage	20 min
	10:40	Coffee		20 min
	11:00	Factors Important in the Selection of Mapper Parameters	Landgrebe	20 min
	11:20	Currently proposed Thematic Mapper System Parameters	Weinstein	20 min
	11:40	The ERIM Study (Note 1)	Legault	20 min
	Lunch			
	1:30 P.M.	Summarization of Tradeoffs and Viewpoints From the Standpoint of:		
		The Sensor	Holmes	15 min
		Data Processing	Viglione	15 min
		Earth Surface Cover and Users	Shay	15 min
	2:30	Assignment of Sub-groups		

Work of sub-groups to continue through Thursday P.M.

A sub-group status review will be held at noon on Thursday. Sub-panel reports will be presented and final recommendations determined on Friday.

Note 1. Multispectral Scanner Data Applications Evaluation Study - Outlines parametrically the trade-offs between user performance requirements and hardware performance and limitations, e.g. spectral bands, spatial resolution, sensitivity.

FIGURE C-2

THEMATIC MAPPER WORKING GROUP
SUBGROUPS

SUBGROUP 1

Holmes, Leader
Hovis
Laverty
Billingsley
Erickson
Wiegand
Blair
Steiner

SUBGROUP 2

Shay, Leader
Potter
Koso
Haralick
Bernstein
Salomonson
Bauer

SUBGROUP 3

Viglione, Leader
Thomson
Norwood
Cheeseman
Wigton
Hoffer
Morain
Ebert

SUBGROUP 4

Simonette, Leader
Nichols
Lowe
Swain
Ungar
Draeger
Castruccio
Rouse

Note: Names underlined indicate members of the Consolidation Panel

FIGURE C-3

RESOURCE PERSONS PRESENT

Mr. Leonard Jaffe
Deputy Associate Administrator, Office of Applications
NASA Headquarters, Code ED 202/775-8606
Washington, D. C. 20546

Mr. William Stoney
Director, Earth Observations Programs
NASA Headquarters, Code ER 202/755-8590
Washington, D. C. 20546

Mr. Richard Legault
Vice President, Environmental Research Institute
of Michigan
The University of Michigan, Post Office Box 618
Ann Arbor, Michigan 48107 313/483-0500

Mr. Oscar Weinstein
Thematic Mapper Project Manager
NASA Goddard Spaceflight Center , Code 726.
Greenbelt, Maryland 20771 301/982-4108

RESUMES

Marvin E. Bauer
Program Leader
Crop Inventory Systems Research
Laboratory for Applications of Remote Sensing
Purdue University
West Lafayette, Indiana 47906 317/749-2052

B.S.(Ag Econ)	1965	Purdue University
M.S.(Agr)	1967	Purdue University
Ph.D., Crop Physiology & Production	1970	University of Illinois

Dr. Bauer has been a research agronomist at LARS/Purdue since 1970. He had major roles in the design, execution, and analysis of results from the Corn Blight Watch Experiment and the Crop Inventory Technology Assessment for Remote Sensing (CITARS) Experiment. He has also analyzed LANDSAT data from several states for crop identification and acreage estimation and is the principal investigator for a LANDSAT follow-on project. Currently, he is the technical leader of the Field Measurements of Wheat Experiment being conducted by LARS, NASA, USDA, ERIM, and Texas A & M and co-leader of spectral strata definition research at LARS.

He is the author or co-author of 12 papers on remote sensing of crops and has recently completed a review "The Role of Remote Sensing in Determining the Distribution and Yield of Crops" to be published in Advances In Agronomy in 1975.

Professional Societies: American Society of Agronomy and American Society of Photogrammetry.

Ralph Bernstein
Senior Engineer, Manager of Advanced Image Processing Department
IBM Corporation, Federal Systems Division, 18100 Frederick Pike
Gaithersburg, Maryland 20760 301/840-6291

B.S.E.E.	1956	University of Connecticut
M.S.E.E.	1960	Syracuse University

Ralph Bernstein was a principal investigator on the LANDSAT-I (ERTS-I) Program. His investigation addressed the problem of digitally processing the MSS and RBV data to correct the geometry and radiometry to the highest degree possible; and to configure efficient image processing systems to accomplish these objectives. He has also developed techniques to digitally mosaic multiple MSS scenes. He has also been involved with several remote sensing information extraction research activities that have dealt with digital data enhancement and information extraction. This has contributed to a copper ore discovery in Pakistan. He is responsible for an IBM research program dealing with developing advanced image processing technology.

He has published a number of papers in the field of digital image processing, information extraction, geoscientific data acquisition for oceanography, and automatic process control.

He has received the NASA Exceptional Scientific Achievement Award, 1974 and IBM Outstanding Contribution Award, 1974.
Professional Societies: IEEE, Senior Member, ASP Member.

Frederick C. Billingsley
Group Supervisor, Earth Resources Image Processing
Jet Propulsion Laboratory
4800 Oak Grove
Pasadena, California 91103 213/354-4321

B.C.H.E.	1942	Rensselaer Polytechnic Institute
B.E.E.	1947	Rensselaer Polytechnic Institute
M.E.E.	1951	Rensselaer Polytechnic Institute

Fred Billingsley is presently Supervisor of the Earth Resources Image Processing Group, responsible for image processing for ERTS, and other remote sensing investigations involving geologic structure in Arizona (with A.F.H. Goetz, JPL), location of mineralized areas in Nevada (with L.C. Rowan, USGS), water studies (J.R. Apel, NOAA and J.Gackstetter, EPA), earthquake hazard study (for USGS, with D.L. Lamar, CalEsco), and others.

He has about 30 publications and/or presented papers on digital image processing hardware, software, and techniques.

Professional Societies: Member of the NASA Advanced Imager and Scanner Working Group. Member of NASA Discipline Panel on Interpretative Techniques. Co-investigator on Apollo Lunar Multispectral Photography Experiment S-158), the ERTS Arizona Geologic Mapping Experiment, and currently co-investigator on four ERTS-B investigations. Associate editor of Computer Graphics and Image Processing Journal. Senior member of I.E.E.E., and a member of the Society for Photographic Scientists and Engineers, Eta Kappa Nu, and Sigma Xi. Registered professional engineer in the State of New York.

Byron O. Blair
Professor
Crop Ecology, Agronomy Dept. and LARS
Purdue University, Lafayette, Indiana 47907 317/749-2052

B.S.	1947	Fort Hays Kansas State College
M.S.	1948	Fort Hays Kansas State College
Ph.D.	1954	Cornell University

Byron Blair is a Project Leader in NASA supported study of green and brown wave development of permanent vegetative cover at 14 locations in Appalacian and Mississippi Valley corridor 1972-73. Currently working on projects in LACIE and LANDSAT 2 at LARS.

His publications are confined to studies of permanent vegetative cover and its reactions to over graying; also use of perennial plant species and observation of their phenophase development over time, and such relationships to predicting economic crop development and yields. He has worked with climate data in predicting crop yields. Publications in those areas - 6 total.

Peter A. Castruccio
President, Ecosystems International, Inc.
P. O. Box 225
Gambrills, Maryland 21054 301/987-4974

B.S., Physics	University of S. Paula
Dr., Engineering	University of Genova
Physics	John Hopkins University

Dr. Castruccio was the Director of the Westinghouse Astronautics Institute in 1958, originating the concept of dealing with Space Strategy and the Art of War on Space in our Air Force SR's. In 1961 he joined IBM and in 1962 became the Director for Advanced Space Programs. In the past ten years he repeatedly has been involved in studies on user-oriented space systems for the study of the earth's resources, water resources, air pollution and ecological and food supply problem. Currently, he is involved in analysis of remote sensing in the management of natural resources as the President of Ecosystems International, Inc.

He has authored over 50 publications on space, environment, space applications, natural resources, radar and communication systems design. He served as consultant to the United Nations in 1967. He was named "one of the ten outstanding young men of the nation" by the U.S. in 1969. In 1973, Dr. Castruccio received the "Golden Olive Branch" for his accomplishments by foreign citizens of Italian origin, Italian Chamber of Commerce. He is a Senior Member, IEEE; Associate Fellow, AIAA; Senior Member, AAS.

Charles F. Cheeseman, Jr.
Manager, Mission and Applications Program
General Electric - Space Division , P.O. Box 8661
Valley Forge, Pennsylvania 19101 215/962-4728

B.S.E.S.	1962	United States Air Force Academy
M.S. Sys. Eng.	1969	University of Pennsylvania
Ph.D. Sys. Eng.	1973	University of Pennsylvania

Dr. Cheeseman has performed systems requirements and design studies of Earth Resource systems for the past six years. He is currently leading the Total Earth Resources for the Shuttle Era study at GE and several other system design efforts. From 1970-72, he was the System Engineer of the SKYLAB radiometer/scatterometer/altimeter instrument (S-193) which flew successfully in 1973. His Ph.D. thesis subject was "A Cost/Performance Analysis of Aircraft and Satellites as Earth Resources Platforms."

He has authored several other publications dealing with remote sensing systems analysis and designs.

Professional Societies: Member of the AIAA.

William C. Draeger
Principal Applications Scientist - Agriculture
Technicolor Graphic Services, Inc.
South Dakota Operations - EROS Data Center
Sioux Falls, South Dakota 57198 605/594-6511

B. S., Forestry	1964	University of California, Berkeley
M.S., Forestry	1965	University of California, Berkeley
Ph.D., Wildland Resource Science	1970	University of California, Berkeley

William Draeger is a project leader on numerous NASA-funded (and other) investigations regarding application of aerial and space data to forestry, agriculture, and water resources. e.g. forest mapping using ERTS in tropics (FAO-Columbia), use of aerial photos in water quality monitoring, agricultural inventories using ERTS data, snow areal extent estimation, wildland multiple-use planning. Emphasis on definition of operational user requirements for resource data from remote sensing. Served as member, NASA ERTS-B proposal review committee, N.A.S. Vietnam Herbicide review group. Currently involved in training and technology transfer to remote sensing applications user community.

He is the author/co-author of over 30 articles and reports relating to above mentioned projects.

Professional Societies: Member, American Society of Photogrammetry, Society of American Foresters, Xi Sigma Pi.

Donald H. Ebert
Head of Systems Engineering Group
Bendix Aerospace Systems Division
3300 Plymouth Road
Ann Arbor, Michigan 48107 313/665-7766

B.S. E.E.	1952	Illinois Institute of Technology

Donald Ebert is engaged in remote sensing activities now and since 1969. As project engineer of the MSDS-24 channel scanner ground data processing system developed the first all digital multispectral scanner recording and processing system. Subsequently involved in analysis, design, and development of digital data processing systems for satellite and airborne multispectral data systems. In 1973, program manager of the NASA-GSFC EOS Conical Scan Impact Study. Recently member of an IAF working group on Receiving, Processing and Dissemination of Earth Resources Satellite Data whose report is being distributed to all UN Member Nations. Presently head of the systems engineering group responsible for analysis and design of all Earth Resources--Remote Sensing Systems.

He has published three technical papers.

Professional Societies: Member of IEEE.

Jon D. Erickson
Head, Information Systems and Analysis Department and Senior Research Engineer
Environmental Research Institute of Michigan
P.O. Box 618
Ann Arbor, Michigan 48107 313/483-0500

B.S.E.	1959	University of Michigan
M.S.E., Nuc. Eng.	1962	University of Michigan
Ph.D., Nuc Eng.	1966	University of Michigan

Jon Erickson is active in information technique and hardware development for multispectral scanner earth resources survey information systems applications since 1969. Dr. Erickson's specific previous experience with multispectral scanner engineering and performance evaluation from data analysis was obtained on (1) the ERIM M-5 MSS through an effort at performance determination and calibration, (2) the study of optical transfer techniques for orbital scanners, scanner calibration, and detector utilization in line scanners, (3) the 24-channel MSDS including evaluation flight planning and ground data correlation, (4) the ERIM M-7 through a program of systematic monitoring and evaluation of performance and data quality, (5) an evaluation of multi-aspect MSS, (6) the Skylab EREP S-192 sensor performance evaluation including frequency response and noise reduction filtering, and (7) a systems study of requirements for EOS from MSS data application evaluation including both user applications and sensor systems aspects.

He has published in the fields of neutron spectroscopy, communications and automatic control, lidar, astrodynamics, optical and infrared signatures and signal processing, and remote sensing of environment with emphasis on practical automatic information extraction particularly with multispectral scanner pattern recognition, signature extension, and real time, low cost, parallel digital processing systems.

Professional societies: He is a member of the American Physical Society, American Nuclear Society, American Association for the Advancement of Science and the Association for Computing Machinery.

Robert M. Haralick
Associate Professor of Electrical Engineering
Remote Sensing Laboratory
Space Technology Building
University of Kansas
Lawrence, Kansas 66045 913/864-3542

B.A. Math	1964	University of Kansas
B.S.E.E.	1966	University of Kansas
M.S.E.E.	1967	University of Kansas
Ph.D.	1969	University of Kansas

Robert Haralick has been with the Remote Sensing Laboratory at Kansas University since 1966 working with radar imagery, aerial photography, MSS, and satellite imagery. He has been responsible for the development of KANDIDATS (Kansas Digital Image Data System), a complete image processing system on a 32K minicomputer. Research interest has included measures for textural features, clustering procedures, and classification procedures which use spatial information.

He has authored a number of publications in the area of automatic processing of remotely sensed imagery data.

Roger M. Hoffer
Professor of Forestry, and Leader, Ecosystems Research Program, LARS
Dept. of Forestry and Natural Resources
Purdue University
West Lafayette, Indiana 47906 317/749-2052

B.S., Forestry	1959	Michigan State University
M.S., Watershed Mgt.	1960	Colorado State University
Ph.D. Watershed Mgt.	1962	Colorado State University

R. M. Hoffer has been involved full time in remote sensing research since 1964, and was a co-founder of LARS in 1966. His special interests involve the interpretation and analysis of multispectral scanner data and color infrared photography, with particular emphasis on study of the spectral characteristics opment of effective computer-aided analysis techniques using multispectral scanner data, particularly for forestry, water resource, and land use applications. He has served as a principal investigator in the LANDSAT and SKYLAB programs, and participated in the EOS Payload Discussion Group in November 1973. Dr. Hoffer teaches three courses in remote sensing of natural resources.

He is the author or co-author of over 50 scientific publications or papers on remote sensing. He has presented invitational papers at international and national symposia and meetings in numerous countries throughout South America, Southeast Asia, and Europe.

Professional Societies: He is a member of the Society of American Foresters, American Society of Photogrammetry (where he currently serves as First Deputy Director of the Remote Sensing and Interpretation Division), Ecological Society of America, Sigma Xi, and several other professional and honorary societies. He is also listed in American Men and Women in Science.

Roger A. Holmes
Dean, College of Engineering
University of South Carolina
Columbia, South Carolina 29208 803/777-4177

B.Sc.	1953	U.S.Coast Guard Academy
M.Sc. E.E.	1958	M.I.T.
Ph.D.,E.E.	1962	Purdue University

Roger Holmes entered remote sensing in 1965 at Purdue University, Co-PI with Roger Hoffer on the first LARS contract, 1966. Program leader of the measurements group, LARS, 1966-1970. Member of the ground truth advisory group, ERTS-A/EREP proposal review, 1971. Chairman of the NASA/JSC working group, Earth Observations Division, 1973 to present. Conference speaker at the UN/FAO Remote Sensing Symposium, Cairo, Egypt, September, 1974.

He has published five remote sensing papers and two LARS Information Notes.

Professional Societies: He is a member of IEEE.

<u>Warren A. Hovis Jr.</u>
Associate Chief, Earth Observations Systems Division
NASA, Goddard Space Flight Center, Code 940
Greenbelt, Maryland 20771 301/982-6465

A.B., Physics	1953	Johns Hopkins University
Ph.D., Physics	1961	Johns Hopkins University

Previously a senior scientist, Jet Propulsion Laboratory in remote sensing of planetary atmosphere and surfaces. At GSFC, laboratory measurement of spectral character of natural materials, reflectance, absorption from ultra violet to far IR. Field measurements of spectral character of natural materials. Principal investigator on Nimbus 4 (Filter Wedge Spectrometer) and Nimbus 5 (Surface Composition Mapping Radiometer). Presently engaged in aircraft measurements of ocean color for use in developing Nimbus G Coastal Zone Color Scanner (CZCS) data processing techniques as Senior Scientist for CZCS and thermal scanning for development of data processing techniques for use with Heat Capacity Mapping. Project Scientist, Heat Capacity Mapping Mission.

He has published about 20 publications on optical properties of natural materials in visible and infrared measured in laboratories and from aircraft.

<u>D. Alexander Koso</u>
Director of Research and Engineering
Honeywell Incorporated
Radiation Center
2 Forbes Road
Lexington, Massachusetts 02173 617/862-6222

B.S., M.S.E.E.	1957	M.I.T.
Elect. Eng.	1959	M.I.T.

Alexander Koso is responsible for design of various radiometers and spectrometers including S-192 and effort on the EOS Thematic Mapper Breadboard.

He has published several reports and has authored 1 book on the subject of various S-O instruments.

Professional Societies: Member of IEEE

<u>Norman P. Laverty</u>
Senior Staff Engineer
TRW Systems Group
One Space Park
Redondo Beach, California 90278 213/535-2036

B.S.E.E. 1940 University of California

Norman Laverty is the manager of a project at TRW Systems for development of multispectral camera using silicon phototransistor arrays for earth resources applications. Under contract to Ames Research Center, managed a program for proving the feasibility of obtaining imagery of the outer planets from a spinning spacecraft using a solid-state spin-scan electronic camera. Responsible for pre-contractual study and preparation of proposal to the NASA for a High Resolution Pointable Imager using high-density silicon photodiode arrays. Participated in numerous studies under contract to the NASA for earth resources payload configurations in both unmanned and manned spacecraft.

He is the author of three reports on design and performance of electronic camera systems for remote sensing from space.

Professional Societies: He is a member of Tau Beta Pi and Eta Kappa Nu Honor societies; Associate member of Sigma Xi. Professional Engineer (Electrical and Mechanical), State of California. Member of IEEE, OSA, and AIAA (Associate Fellow).

Donald S. Lowe
Deputy Director
Infrared & Optics Division
Environmental Research Institute of Michigan
P.O. Box 618
Ann Arbor, Michigan
313/483-0500

A.B.	1946	Duke University
M.A.	1948	Duke University

Donald Lowe joined the Naval Ordnance Laboratory where he was responsible for infrared and optical instrumentation development and spectroradiometric measurements of targets and backgrounds. In 1958, he joined the Bendix Aerospace Systems Division where he was responsible for developing airborne spectroradiometric instrumentation systems and remote sensing in earth resources. In his six years at ERIM, he has pioneered the development of multispectral scanning systems with automated spectral pattern recognition and their application to earth resource problems. Chaired the Electromechanical Sensor Panel of Advanced Imagers and Scanners Working Group (Dec. 1972); Member, CORSPERS Ad Hoc Panel on Information Management Panel (1973); Principal Investigaror for program to define earth resource requirements for SEOS (1973).

He is the author of over 20 reports and papers in Remote Sensing.

Professional Societies: Fellow of the Optical Society of America. Member, American Society of Photogrammetry.

Stanley A. Morain
Manager Remote Sensing Program
Technology Application Center
University of New Mexico
Albuquerque, New Mexico 87131
505/277-3622

B.A.	1963	University of California, Riverside
Ph.D.	1970	University of Kansas

Stanley A. Morain was a Research Assistant, University of Kansas Center for Research, Inc. Focus on remote sensing of natural vegetation, agriculture and soils using radar, photographic infrared, multiband photography and multispectral scanners from 1964 through 1970. From 1970 through 1974, he was Research Associate, The University of Kansas Center for Research, Inc., Remote Sensing Laboratory. Principal Investigator on (1) radar sensing for agriculture and the development of an agricultural information system, (2) derivation of wheat acreage, yield and production from satellite imagery. From 1974 to the present, he is the manager, Remote Sensing Program, Technology Application Center, University of New Mexico.

He has published approximately 30 journal articles, technical reports and research papers on the use of remote sensing as applied to natural vegetation, agriculture and soils. All of these publications stem from research supported by NASA, NSF or USGS grants and contracts. As a result of these efforts, he has been invited to participate in several international workshops and training programs in remote sensing for agriculture.

Professional Societies: He is a member of the American Society of Agronomy, Soil Science Society of America, Association of American Geographers, Ecological Society of America, American Society of Photogrammetry, American Institute of Biological Sciences, American Geographical Society.

James D. Nichols
Director
Remote Sensing Research Program
260 Space Sciences Laboratory
University of California
Berkeley, California 94721 415/642-2351

B.S., Forestry	1970	University of California, Berkeley

James Nichols is the director of the program at Berkeley involved in the development of applications of aircraft and spacecraft multispectral scanner imagery. These applications include agriculture, range, forestry, and land use. The emphasis has been placed on multistage sampling procedures appropriate to the user requirements.

He has published approximately 25 publications and reports associated with remote sensing over the past 5 years.

Professional Societies: Life time member of Xi Sigma Pi National Forestry Honor Society and Member of ASP & SPSE.

Virginia T. Norwood
Senior Scientist
Space and Communications Group
Hughes Aircraft Company
P.O. Box 92919
Los Angeles, California 90009 213/648-1666

B.S., Math and Physics	1947	M.I.T.

Mrs. Norwood was study manager for the MSS design study and later in charge of systems engineering through the development stage for MSS launched on LANDSAT I & II. More recently she has conducted studies for designs of advanced sensors relating engineering performance characteristics to user needs.

Her publications include "Scanning Type Imaging Sensors". June 1970. Proceedings of the Princeton University Conference on Aerospace Methods for Revealing and Evaluating Earth's Resources, "Optimization of a Multi-Spectral Scanner for ERTS". October 1969. Proc. VI International Symposium on Remote Sensing. Ann Arbor, Michigan, and "Balance Between Resolution and Signal to Noise Ratio in Scanner Design for Earth Resources Systems". August 1974. Proc. Scanners and Imagery Systems for Earth Observation S.P.I.E. San Diego, CA.

Andrew E. Potter
Chief, Research, Test, and Evaluation Branch
Earth Observations Division , TF3
NASA Johnson Space Center
Houston, Texas 77058
713/483-2071

B.S.	1948	University of Florida
Ph.D., Physical Chemistry	1953	University of Wisconsin

Dr. Potter is currently responsible for management of research test and evaluation in support of the Large Area Crop Inventory Experiment (LACIE). He was technical manager for EREP sensor flight performance evaluation in the Skylab program technical background related to atmospheric effects on remotely sensed data.

He is the author of over 60 papers dealing with combustion science, solar energy, planetary and stellar atmospheres and earth observations.

Professional Societies: Member of AAS, AGU, and AAAS.

John W. Rouse, Jr.
Director, Remote Sensing Center
Professor, Department of Electrical Engineering
Texas A & M University
College Station, Texas 77843
713/845-5422

B.S. E.E.	1955	Purdue University
M.S. E.E.	1965	University of Kansas
Ph.D.	1968	University of Kansas

John Rouse was directly associated with development of remote sensing/ Earth Observations Field with Remote Sensing Laboratory, University of Kansas (1965-68) and Remote Sensing Center, Texas A & M University (1968-present). He conducted research in sensor systems and data analysis in visible and microwave regions and contributed to the literature in the activity areas. Conducted LANDSAT I investigations of rangeland vegetation parameters and selected as LANDSAT II investigator to continue development of rangeland assessment techniques.

His publications include over 40 papers in techical journals and conference proceedings and contributions to two books.

Professional Societies: Institute of Electrical and Electronic Engineers (Senior Member), IEEE Geoscience Electronics Group (President), IEEE Antennas and Propagation Group, American Society of Photogrammetry, AAAS, and Sigma Xi. Listed in American Men of Science and Who's Who in South and Southwest.

Vincent V. Salomonson
Branch Head
Hydrology and Oceanography Branch
Goddard Space Flight Center, NASA Code 913.0
Greenbelt, Maryland 20771 301/982-6481

B.S.	1959	Colorado State University
B.S.	1960	University of Utah
M.S.	1964	Cornell University
Ph.D.	1968	Colorado State University

Vincent Salomonson has had 10 years experience using remote sensing in atmospheric science and water resources with emphasis on satellite remotely sensed data.

He has 40 journal articles and reports in the field of atmospheric science and water resources.

Professional Societies: American Meteorological Society, American Geophysical Union, Sigma Xi and Phi Kappa Phi.

J. Ralph Shay
Assistant Dean of Research
Oregon State University
Corvallis, Oregon 97331 502/754-3451

B.S., Agriculture	1939	University of Arkansas
M.S., Plant Pathology	1941	University of Wisconsin
Ph.D., Plant Pathology	1943	University of Wisconsin

Research in remote sensing of agricultural crops and detection of plant disease stress, 1963-1966. Chairman of National Academy of Science/ National Res. Council Committee on Remote Sensing in Agriculture and Forestry, 1961-69. Participant in summer studies and workshops related to earth-oriented satellites for gathering natural resource information 1967-1974. Administrative responsibilities for Remote Sensing research and development 1972 to present at OSU. Oregon representative on Land Resource Inventory Remote Sensing Project, Pacific Northwest Regional Commission, 1974 to present.

He has had numerous publications on plant diseases especially diseases of fruit and vegetable crops.

Professional Societies: He is a member of AAAS, and American Society of Plant Pathology.

David S. Simonett
Professor of Geography, University of California
Santa Barbara, California 805/961-2344

B.S., Ag Chem & Geology	1946	University of Sydney, Austrailia
M.S., Geography	1949	University of Sydney, Austrailia
Ph.D., Geography	1954	University of Sydney, Austrailia

David Simonett is engaged in research and development in remote sensing and resource development and has been since 1963; as a Professor and Associate Director of the Remote Sensing Laboratory, University of Kansas (1963-1969); McCaughey Professor and Head, Department of Geography, University of Sydney, Australia (1970-1971); as Director of the Division of Land Use and Agricultural Applications, Earth Satellite Corporation; (1972-1974); and Chairman, Department of Geography, UCSB (1975).

Published in remote sensing, resource analysis and management, soils, land use and agricultural geography, with some 70 professional papers in major journals and reports. Principal Investigator for Remote Sensing contracts and grants with the National Aeronautics and Space Administration, U.S. Department of the Interior, U.S. Department of Agriculture, Office of Naval Research, Agency for International Development, Council on Environmental Quality and the State of Maryland. He has had experience in remote sensing resource analysis in Iran, Venezuela, Brazil, Greece and Australia.

Honors: Fulbright Travel Award; Distinguished Scientist-Lecturer, National Science Foundation/American Society of Photogrammetry; Meritorious Contributions to Geography Award, Association of American Geographers.

Professional Societies: International Soil Science Society, Soil Science Society of America, American Society of Agronomy, Association of American Geographers, Institute of British Geographers, International Geographical Union, and American Society of Photogrammetry.

Bruce W. Steiner
Administration 1002
Bureau of Standards
B-312, Metrology
Washington, D. C. 20234 202/921-3138

A.B.	1953	Oberlin College
Ph.D.	1957	Princeton University

Bruce Steiner served as Chief of the NBS interdivision task group for the Candela from 1969 to 1971. He was the U.S. Representative to the Technical Committee 1.2 on Radiometry and Photometry from 1971 to 1973.

Professional Societies: He was a member of the Commission Internationale de l'Eclairage from 1971 to 1973. He was Founder and the First chairman of the Council for Optical Radiation Measurement in 1972. He was the Chairman of the Technical Group of Radiometry and Photometry of the Optical Society of America from 1973 to 1974.

Philip H. Swain
Program Leader for Data Processing & Analysis Research
Laboratory for Applications of Remote Sensing
Purdue University , 1220 Potter Drive
West Lafayette, Indiana 47906 317/749-2052

B.S.E.E.	1963	Lehigh University
M.S.E.E.	1964	Purdue University
Ph.D.	1970	Purdue University

Dr. Swain has been at the Laboratory for Applications of Remote Sensing, Purdue University, since 1966. He is principally concerned with the application of pattern recognition and related techniques to computer-assisted analysis of multispectral remote sensing data. He has directed the research in this area at LARS since 1970. As consultant to NASA, he has participated in reviewing specifications for the Earth Observational Satellite (EOS) and has reviewed proposals for ERTS follow-on investigations.

Dr. Swain has authored more than six scientific articles in the area of pattern recognition and its application to remote sensing.

Professional Societies: He is a member of Phi Beta Kappa, Sigma Xi, Eta Kappa Nu and the Institute for Electrical and Electronics Engineers.

Frederick J. Thomson
Research Engineer
Environmental Research Institute of Michigan
P.O. Box 618
Ann Arbor, Michigan 48107 313/483-0500

B.S., Elect. Eng.	1961	University of Michigan
M.S., Elect. Eng.	1963	University of Michigan

Frederick Thomson, as deputy director of the Technology Applications Group has participated in several design studies for future remote sensing data collection-processing-dissemination systems responsive to user information needs. During the summer of 1974, he participated in the National Academy of Engineering summer study of future earth resources systems as a member of the Land Use Panel. He has managed a group of about 30 engineers and natural resources scientists in applying computer processing and photo-interpretation to imagery and electronic data from multispectral scanner and camera systems. His work has been focused in the Earth Resources area and includes investigations using data from various airborne scanner systems and ERTS and EREP satellite systems.

He has published twenty-three major publications on remote sensing in military applications of earth resources.

Professional Societies: Member of Eta Kappa Nu and Tau Beta Pi.

Stephen G. Ungar
Space Scientist
NASA Goddard Institute for Space Studies
2880 Broadway
New York, N.Y. 10025
301/474-5603

B.S.	1954	The City College of New York
M.S.	1964	The City College of New York
Ph.D	1971	City University of New York

Dr. Stephen G. Ungar is a staff Research Scientist at NASA's Goddard Institute for Space Studies. His current research efforts are directed toward the development and application of interpretative techniques for LANDSAT and other remote sensing data. Dr. Ungar's principle area of specialization is Astrophysics. He is an Adjunct Professor of Physics at the City University of New York and has served as an Adjunct Professor of Astronomy at Columbia University. Prior to his tenure at the Goddard Institute, Dr. Ungar was an Associate Research Scientist at Columbia University, Hudson Laboratories where he participated, as experimental physicist, in studies with Nuclear Magnetic Resonance, Atomic Absorption and Infrared Spectroscopy.

Dr. Ungar has published several papers in Nuclear Magnetic Resonance and Atomic Absorption Spectroscopy as well as paper in stellar structure and evolution.

Professional Studies: He is a member of the American Physical Society, American Association of Physics Teachers, and American Astronomical Society.

Sam S. Viglione
Manager, Earth Information Sciences
McDonnell Douglas, Building 28
5301 Bolsa Avenue
Huntington Beach, California 92647
714/896-5165

B.S. E.E.	1954	Carnegie Institute of Technology
M.S. E.E.	1956	University of Southern California

Sam Viglione became involved in the field of remote sensing early in his career with the study of satellite borne imaging and sensing systems for military reconnaissance. In the late 50's and early 60's he investigated the use of active imaging systems for target identification as well as passive systems for both active and passive radiation measurements. Early in the 60's the work promoted his interest in the automatic target recognition problem associated with radar and photographic image processing. Since 1961, he has directed the pattern recognition technology development at MDAC with specific application to target recognition and later in 1965-66 to earth resources imagery analysis. He has developed both analytic and hardware systems for image processing, including man-machine image processing system with interactive capability through a variety of display and processing options callable from menus displayed on an interactive terminal.

He is the author of over 25 papers and textbook materials on pattern recognition and its applications, including image processing pertinent to earth information monitoring. He has participated in numerous related symposia, workshops and planning groups including the 1967-68 Wood Hole Summer Study, "Benefits of Earth Satellites for Mankind" and the 1974 Snowmass Summer Study "Practical Application of Space Systems".

Craig L. Wiegand
Soil Scientist and Technical Advisor for Remote Sensing, USDA-ERS
P.O. Box 267
Weslaco, Texas

B.S., Agronomy	1955	Texas A & M University
M.S., Agronomy	1956	Texas A & M University
Ph.D., Soil Physics	1960	Utah State University

Craig Wiegand has been active in investigations of remote sensing applications in Agriculture since 1963. Principal Investigator on ERTS-1 and LANDSAT II contracts with NASA. Both deal primarily with vegetation mapping using machine methods. With Weslaco colleagues he has published or has in various stages of publication processing approximately 10 technical articles dealing with use of MSS responses to detect vegetation density variations, vegetation stress, and crop classification. Participated in the International Remote Sensing Workshop in 1971, and presented a paper on agricultural uses in infrared scanners. Active member of Great Plains Council subcommittee on remote sensing; group is interested in energy balance approach to evapotranspiration.

William H. Wigton
Mathematical Statistician
United States Department of Agriculture
Statistical Reporting Service
Washington, D.C. 20250

B.S.	Marietta College
M.S.	North Carolina State University

William Wigton was the principle investigator for follow-on agreement in 1975 making an area sampling frame for Nicaragua from LANDSAT imagery. From 1972 to present he has been working an ERTS-1 investigation for NASA by USDA Statistical Reporting Service on Crop Classification and Acreage Measurement.

He has several publications in statistical journals and remote sensing symposium journals.

APPENDIX D

LETTER OF INVITATION

APPENDIX D
Letter of Invitation

Dear :

You are invited to participate in a Thematic Mapper parameter review meeting to be held at Purdue University April 30, May 1 and 2, 1975; about 30 scientists and engineers will be participating.

As you may know, a significant amount of research and several previous review meetings have been useful in delineating preliminary performance specifications for this instrument. It will be the task of this group to undertake a final review of these specifications prior to NASA entering the final design and development phase for the flight hardware, planned for later this year.

More specifically, the group is being asked to:

1. Review and provide recommendations on current specifications for the Thematic Mapper.
    a. Spectral band locations and widths.
    b. Sensitivity, dynamic range and S/N.
    c. Spatial resolution.
    d. Image data geometric accuracy.
2. Provide information on the impact of tradeoffs regarding
    a. Temporal frequency of observations.
    b. Image data spatial sampling schemes.
    c. Conical vs. rectilinear scan.
    d. Thermal IR band resolution being factor of 3 greater than visible/reflective IR bands.
    e. Atmospheric effects; effects on geometric accuracy if sensor is mounted off-axis (canted).

The basis (or performance criterion) on which these system specifications are to be selected is the classification accuracy of a machine data analysis system when utilized in vegetation mapping tasks.

Using the above criteria and the enclosure, you are requested to provide a position paper stating your views on the present Thematic Mapper specifications and the rationale for your opinions. This paper should not exceed 1000 words, and should be forwarded to Dr. Landgrebe no later than April 11, 1975.

There are, of course, some boundary conditions imposed by budget, the state of technology, and other related factors. These are apparent from the attachments on

1. Mission objectives.
2. Mission description.
3. Spacecraft description.
4. Thematic Mapper description.

Instrument related constraints are

1. Six spectral bands (1 thermal).
2. Optics which provide an IFOV in the 30-50 meter range

We look forward to your early acceptance of this invitation and your participation at the meeting. Upon receipt of your intention to attend, addressed to Dr. Landgrebe at the address below, we will forward additional information about the agenda, the physical arrangements, travel and accomodations.

Dr. David A. Landgrebe
Laboratory for Applications of Remote
Sensing/Purdue University
Purdue Industrial Research Park
1220 Potter Drive
West Lafayette, IN 47906

David A. Landgrebe, Chairman

Richard A. Moke, NASA Co-chairman

Attachment to Invitation Letter

EOS MISSION OBJECTIVES

The Thematic Mapper is to provide remotely sensed data that will improve our capability to (1) detect, classify, monitor, and manage vegetative cover, (2) predict crop productivity, (3) improve inland water resource utilization, and (4) determine land use change.

The mission objectives dictate that the EOS instrument be optimized for the automatic identification of vegetative species and for the determination of the vigor of the vegetative cover.

Potential applications of this information can be in the areas of:

Forecasting of major crop commodities.
Survey of short-term local crop productivity.
Mapping of agriculture land use.
Monitoring rangeland.
Surveying forest resources.
Watershed and water use management.
Land use change detection.

DESCRIPTION OF EOS SYSTEM

Overview

The EOS system as currently planned by NASA is expected to provide an evolutionary but marked improvement in remote sensing performance over Landsat 1, 2 and C. For example, higher radiances and smaller values of minimum discriminable reflectances for automatic categorization of vegetative cover will be provided, together with finer spatial resolution and more frequent temporal sampling; also, registration will be adequate for change-detection without significant loss of resolution.

Mission Parameters

. Orbit time-of-day:	11:00 a.m., descending node
. Repeat cycle:	One of two approaches will be taken to achieve a 7-to 9-day repeat cycle: (a) Single satellite, two scanners together covering a 370-km swath.

(b) Two satellites, suitably phased (probably launched one year apart) with one or more scanners covering a 185-km swath from each satellite.

Approach (a) offers the additional option of allowing a second satellite launch to provide 3-to 5-day repeat coverage. The corresponding orbital altitudes chosen are: (a) 705.3 km; (b) 702.4 km.

Propulsion will be provided for refurbishment of orbital altitude.

Spacecraft

The EOS spacecraft will incorporate features such as:

- Modularity of subsystems.
- Commonality among several other NASA missions.
- Compatibility with Space Shuttle launch, retrieval and (for later missions) resupply in orbit.
- Compatibility with conventional launch vehicles in pre-Shuttle era (prior to 1983).
- Improved accuracy and stability of pointing (0.01 degree and 10^{-6} degree/second).
- Data link to ground (both direct and via the Tracking and Data Relay Satellite System) will have a 240 Mb/sec maximum capability at a 10^{-5} bit error rate.
- EOS/TDRSS will provide world-wide acquisition and relay capability.

Ground Data Handling

- Accurate band-to-band registration provided by suitable instrument design and by spacecraft stability.
- Spacecraft stability will permit geometric corrections to be made such that pass-to-pass (pass ≃ 100 x 1000 n.mi.) registration can be made by using only about six ground control points distributed over the entire 10^{-5} square-mile pass.
- Turn-around time: 48 to 72 hours as throughput varies from 10^{11} to 10^{12} bits per day.

THEMATIC MAPPER INSTRUMENT

Parameter	A[1]	B[2]
. Swath width	185 km	185 km
. IFOV Footprint on ground (visible - reflective IR)	30 meters	30-40 meters
. IFOV Footprint width on ground (thermal band)	100-160 meters	
. Number of spectral bands	5 visible-reflective IR 1 thermal	5 visible-reflective IR 1 thermal
. Placing of spectral bands	0.5-0.6μm 0.6-0.7 0.7-0.8 0.8-1.1 1.55-1.75 <u>or</u> 2.08-2.35 10.4-12.6	0.45-0.52μm 0.52-0.60 0.63-0.69 0.80-0.95 1.55-1.75 10.4-12.5
. Look direction	fixed (not necessarily NADIR)	fixed (not necessarily NADIR)
. NEΔρ		.002 to 0.1 (ie 0.2 to 1.0 percent)
. NEΔT	0.5 K	
. Spatial sampling rate		1.4 IFOV (Along scanlines)
. Data Word	7 bits	8 bits

[1] Spectral bands recommended by the EOS Payload Discussion Group. (EOS PDG), November, 1973.

[2] Spectral bands and spatial resolution resulting from JSC/ERIM study "Multispectral Scanner Data Application Evaluation," December, 1974.

Appendix E

Subgroup 1 Report

R. HOLMES	(LEADER)
W. HOVIS	(CONSOLIDATION PANEL)
N. LAVERTY	
F. BILLINGSLEY	
J. ERICKSON	
C. WIEGAND	
B. BLAIR	
B. STEINER	

PANEL #1 REPORT

Spectral Band Locations and Widths - The band locations, widths, and priorities established by Panel #1 are:

Of equal and top priority:

0.52-0.60 μm [4,8,10,12,15]
0.63-0.69 or 0.62-0.68 μm [1,3,4,5,8,9,10,11,12,15]
0.74 or 0.75-0.90 μm [1,2,3,4,7,8,9,11,12,15]

Next and near top priority:

10.14-12.5 μm [6,7,13,14]

Next and near top priority:

1.55-1.75 μm [1,3,7,11]

Of low priority for quasi-operational work:

0.45-0.52 μm [7]
2.08-2.35 μm [6,10]

The 0.62-0.68 μm alternative centers on the 0.65 μm chlorophyll band a bit better than the 0.63-0.69 μm choice, but the panel feeling is not strong on this point; either selection is acceptable.

The 0.74 or 0.75 μm to 0.90 μm choice is made to avoid the 0.92 μm water band [16] and capture data closer to the beginning of the vegetative high NIR reflectance, which the agricultural users state is an early indicator of plant stress. [17]

The priority of the first four bands is founded on the experience base that comparable (though not exactly equal) bands on LANDSAT-C will generate in the user community.

The 1.55-1.75 μm band is known to be indicative of leaf water content on the basis of differential comparisons with the 0.74-0.90 NIR reflectance of leaves.[17]

The bands at 0.45-0.52 μm and 2.08-2.35 μm were considered to be of interest in a research program but of questionable marginal value in a quasi-operational sense. The utility of the 0.45-0.52 band in conifer/deciduous discrimination was pointed out.[18] On the order of 50% at best of the instrument irradiance in the 0.45-0.52 μm will be from the earth surface; the rest is predominantly Rayleigh backscatter. The photon budget in the 2.08-2.35 μm band is sparse, and the information gained for both soils and vegetation is probably available in the 1.55-1.75 μm band. If there is to be another band aboard the EOS thematic mapper, the majority of the panel favored the 0.45-0.52 over the 2.08-2.35, but there was sentiment the other way based on geological and soil considerations.

Sensitivity, Dynamic Range, and S/N - The panel recognized that once spectral bands were selected, the remaining trade-offs were between spatial resolution as stated in an MTF specification, and signal-to-noise ratio as stated in NE$\Delta\rho$ or NEΔT. (We chose to avoid the atmospheric modelling necessary to translate these noise equivalencies to noise-equivalent-radiance at the top of the atmosphere.) Consideration was given to the position paper which pointed out the relative effects of MTF and NE$\Delta\rho$ on error. An SR&T task was identified:

> Given a certain classification task, errors arise in the classification due to the statistical variability of the scene, the statistical variability of the atmosphere, the

statistical variability of the electronic noise in the system including quantization noise, and the edge effects from the finite (and fuzzy) IFOV footprint. Determine the functional dependence of the probability of misclassification for the given task on (1) MTF or some equivalent measure of spatial resolution and (2) NE$\Delta\rho/\Delta T$ or some equivalent measure of signal-to-noise ratio:

$$\text{Prob. of Misclassification} = f(\text{MTF}, \text{NE}\Delta\rho/\Delta T)$$

Then find

$$\frac{\partial f}{\partial \text{MTF}} \text{ and } \frac{\partial f}{\partial \text{NE}\Delta\rho/\Delta T}$$

and work on or emphasize the partial derivative with the largest value. Bear in mind that the probability of misclassification is also a function of the <u>task</u>

$$\text{Prob. of Misclassification} = F(\text{TASK},\text{MTF},\text{NE}\Delta\rho/\Delta T)$$

In the opinion of the panel, NE$\Delta\rho$ should be 0.005 and NEΔT should be 0.5°K at 300°K as first priorities [18]; then the spatial resolution should be as good as possible consistent with the other instrument constraints such as number of detectors, aperture size, data rate, and so on.

<u>Spatial Resolution</u> - The panel felt the resolution should be bounded by 30 m and 90 m and should be as close to 30 m as possible consistent with the NE$\Delta\rho/\Delta T$ choices above. [19]

Image Data Geometric Accuracy - A precision of 0.1 pixel within a frame array is desired. Efforts should be made to avoid frame-to-frame rotation over the same site at different passes, in order to ease the task of temporal overlay. That is, the satellite heading should be stabilized as much as possible. Current specification of +0.01° absolute will give a ±16 m or +0.5 pixel at the middle of the frame sides, $\sqrt{2}$ worse at the corners.

Temporal Frequency of Observations - The panel choice was two satellites, 9-day repetition. The two-scanner system was deemed less satisfactory because of the 3-day weather correlation and because of the increased atmospheric variabilities due to larger cant angles.[20] The agricultural user members feel that 9-day repetitive coverage must be coupled with very rapid data delivery (36-72 hours) in order to achieve maximum classification accuracy.[21] The thermal band should be used for night as well as day operation. The larger cant angles will cause significant terrain relief displacement. 11:00 a.m. in the mission parameters was considered to be the latest possible time due to fair weather cloud buildup caused be diurnal heating.

Image Data Sampling Schemes - The 1.4 IFOV along scan and the 1.0 IFOV along track were deemed reasonable. The 1.4 IFOV is a reasonable compromise with Nyquist sampling.

Conical vs. Rectilinear Scan - Rectilinear scanning was preferred over conical scan because:

a) Conical scanning would make direct readout capability more complicated and probably considerably more expensive.

b) The conical scan provides a constant atmospheric path but a change of phase angle (angle between incident sunlight and radiance reflected to scanner) will occur with effects not well understood.

c) The tilt of the conical scan either ahead or behind the spacecraft 14° to 15° will point the scanner directly into the sun glint over water in either the Northern or Southern Hemisphere. This will eliminate any chance of studying sediments in water when the glint is seen.

In general, it was agreed that data should be delivered in rectilinear form regardless of the scan choice.

Thermal IR Band Resolution - A thermal band spatial resolution of 120 meters is considered a detriment as opposed to a registered band with the same spatial resolution as the daylight bands but the practical limitations of diffraction and NEΔT performance are recognized as preventing this. The thermal band is still highly desirable [18,22] and should be available for night as well as day operations.

Atmospheric Effects - Estimation of water vapor effects is desirable but probably not possible with the bands considered for the Thematic Mapper. An experiment is needed to determine if two narrow bands located in and adjacent to the water vapor bands but with coarse spatial resolution can measure water vapor concentration. If feasible, the ratio could be computed on the spacecraft and transmitted at low bandwidths.

Polarization Effects - The polarization specification of 5% is probably too crude. Consideration should be given to a tighter specification to avoid radiometric errors due to polarization effects both at the surface reflection layer and from backscattered radiance from the atmosphere, especially if the 0.45 to 0.52 band is included.

REFERENCES

1. Allen, W. A., H. W. Gausman, and C. L. Wiegand, "Spectral reflectance from plant canopies and optimum spectral channels in the near infrared," 3rd Annual Earth Resources Prog. Rev., NASA MSC, Vol. II, Section 23, pp. 1-15, 1970 (see Figs. 7, 8, 9 pp. 13-15).

2. Cardenas, R., H. W. Gausman, W. A. Allen, and Marcia Schupp, Remote Sensing of Environment, 1:199-202, 1969-70 (see Fig. 6 p. 202).

3. Gausman, H. W., W. A. Allen, R. Cardenas, and A. J. Richardson, "Reflectance discrimination of cotton and corn at four growth stages," Agron. J., 64:194-198, 1973 (see Fig. 6 p. 198).

4. Gausman, H. W., D. E. Escobar, and R. R. Rodriguez, "Discriminating among plant nutrient deficiencies with reflectance measurements," Proc. 4th Biennial Workshop on Aerial Color Photography in the Plant Sciences, Univ. of Maine, Orono., July 10-12, pp. 13-27, 1973 (see Fig. 1 p. 20).

5. Gausman, H. W., A. H. Gerbermann, and C. L. Wiegand, "Use of ERTS-1 data to detect chlorotic grain sorghum," Photogram. Engin., XLI:177-181, 1975 (Plate 1, p. 187).

6. Gausman, H. W. and W. G. Hart, "Reflectance of sooty mold fungus on citrus leaves over the 2.5 to 40 μm wavelength interval," Journ. of Econom. Entomology, 67:479-480, 1974.

7. Richardson, A. J., M. R. Gautreaux, and C. L. Wiegand, "...24 channel MSS CCT land use classification results," Machine Processing of Remotely Sensed Data, Conf. Proc., pp. 2A-33 to 2A-53, 1973 (see p. 2A-39).

8. Richardson, A. J., C. L. Wiegand, H. W. Gausman, J. A. Cuellar, and A. H. Gerbermann, "ERTS-1 Type III Final Report for period 6/9/72 to 11/27/74, NASA Contract S-70251-AG, Task 3, Goddard Space Flight Center, Greenbelt. (See appendix on modeling plant, soil and shadow components of ERTS-1 MSS signals and specifically p. 51 table).

9. Root, R. R. and L. D. Miller, "A computerized field technique for selecting optimum multispectral scanner channels for computerized mapping of surface materials," Incidental report #4, Dept. of Watershed Sciences, Colo. State Univ., Ft. Collins, 100 pp., 1972.

10. Vincent, R. K., R. Horvath, F. Thomson, and E. A. Work, "Remote sensing data analysis projects associated with NASA Earth Resources Spectral Information System, Report WRL-3165-26-T, 55 p., Willow Run Labs, Univ. of Michigan, 1971.

11. Wiegand, C. L., H. W. Gausman, and W. A. Allen, "Physiological factors and optical parameters as bases of vegetation discrimination and stress analysis," Proc. Seminar on Operational Remote Sensing, Amer. Soc. Photog., Falls Church, Va., pp. 82-102 (see Figs. 4 and 5, p. 90 & 91) (approx. 65 references).

12. Wiegand, C. L., H. W. Gausman, J. A. Cuellar, A. H. Gerbermann, and A. J. Richardson, "Vegetation density as deduced from ERTS-1 MSS response," Proc. 3rd ERTS-1 Sympos., Vol. I, Section A, NASA SP-351, U. S. Gov't. Printing Office, Washington, D. C., pp. 93-116, 1974.

13. Wiegand, C. L., "Agricultural applications and requirements for thermal infrared scanners," Proc. Int'l. Workshop on Earth Resources Survey Systems, Univ. of Michigan, Ann Arbor, pp. 66-81.

14. Bartholic, J. F., L. W. Namkem, and C. L. Wiegand, "Combination equations used to calculate actual and potential evaporation," USDA, ARS, Series 41-170, 14 pp., 1970.

15. Goddard Space Flight Center, NASA, EOS Payload Discussion Group, Final Report, EOS-410-09, October 1973. See especially Ag/Range/For recommendations pp. C-5 to C-10 which state rationale and evidence for wavelength selection.

16. Chapman, R. M. and R. Carpenter, "Effect of Night Sky Backgrounds on Optical Measurements," Geophysics Corp. of America Contract No. L-68227, 22 May 1961, p. 25.

17. Leeman, V., D. Earing, R. K. Vincent, and S. Ladd, "The NASA Earth Resources Spectral Information System: A Data Compilation," May 1971;

    Leeman, V., R. Vincent, and S. Ladd, "The NASA Earth Resources Spectral Information System: A Data Compilation First Supplement," 1972;

    Vincent, R., "The NASA Earth Resources Spectral Information System: A Data Compilation Second Supplement," January 1973.

18. Thomson, F., et al., Spectral bands and resolution resulting from JSC/ERIM Study, "Multispectral Scanner Data Application Evaluation," December 1974.

19. Horwitz, H. M., J. T. Lewis, and A. P. Pentland, "Estimating Proportions of Objects from Multispectral Scanner Data," ERIM Report No. 109600-13-F, May 1975.

20. Turner, R. E., et al., "Influence of the Atmosphere on Remotely Sensed Data," Proceedings of the 18th Annual Technical Meeting of Society of Photo-optical Engineers, Scanners and Imagery Systems for Earth Observation, San Diego, August 1974. See attached graphs.

21. Blair, B., Interpretation of Temporal Data from ERTS-1, Demonstrating the Brown and Green Wave Proceedings of the First International Congress of Ecology, The Hague, September 1974, pp. 283-285, NASA Contract No. 5-21781.

22. Corn Blight Watch Experiment, Final Report, Vol. I, II, III, NASA, JSC, 1973-74.

Appendix F

Subgroup 2 Report

RALPH SHAY (LEADER)

ANDREW POTTER (CONSOLIDATION PANEL)

MARVIN BAUER

RALPH BERNSTEIN

ROBERT HARALICK

ALEX KOSO

VINCENT SALMONSON

GENERAL RECOMMENDATIONS

Several topics were discussed which concern the overall system philosophy, particularly as it affects the user and the Thematic Mapper data utility. It is felt that these deserve mention at this time to assure consideration. Of particular importance are questions relating to the data processing and dissemination.

The operational systems of the Thematic Mapper should be thoroughly integrated with a central data processing facility, regional data centers, and small low-cost data centers to provide maximum efficiency and economy in data utilization by state, regional, and foreign users.

Thematic mapper data should be formatted such that it is readily retrievable in a convenient map coordinate reference system.

Data from selected, limited regions, defined by the coordinate system, should be accessible on demand.

Turnaround time should be at least consistent with frequency of observation (i.e. 9 days max.). Every effort should be made to enable 2-3 day turnaround on selected data segments.

Data for selected applications may be required by USDA within 24 hours of the overpass of an area. This may necessitate either improved preprocessing methods or the installation of additional receiving stations and preprocessing facilities.

These, and other questions related to data processing and dissemination must be reviewed at an early date by NASA and the user community in order to realize fully the potential of the Thematic Mapper.

SPECIFIC SUMMARY RECOMMENDATIONS

I A Spectral Band Selection

Recommended bands were:

.45 - .52 micron
.52 - .58 "
.63 - .69 "
.75 - .90 "
1.55 - 1.75 "
10.40 - 12.50 "

Preliminary studies of Skylab S-192 data indicate that the 2.08-2.35 micron band showed details not seen in other bands. Further study of this band is recommended.

Consideration of adding an ultraviolet research band near 0.4 micron and a thermal research band adjacent to the existing thermal band was recommended, along with a research program to define techniques.

IB Sensitivity, Dynamic Range and S/N Ratio

Based on existing data, a value for noise-equivalent reflectance difference ($NE_{\Delta \rho}$) of .005 was recommended, although further study is needed to determine how much this requirement could be relaxed. This requirement leads to an 8 bit individual scene dynamic range, with a 10 bit total sensor dynamic range.

1C Spatial Resolution

A resolution of 39 meters was recommended, on the assumption that the acreages were to be measured primarily for fields larger than 20 acres. This resolution is an even multiple of the uncorrected Landsat resolution (helpful to users with obsolete Landsat processing equipment), and is an odd multiple of the proposed thermal band resolution (helpful for combined processing of thermal and reflective data).

1D Image Data Geometric Accuracy

Requirements are as follows:

	Needed	Achievable
Absolute accuracy	0.5 PXL	0.5 PXL
Internal consistency	0.5	0.4
Temporal (relative accuracy	0.5*	0.5

* Under study by ERIM

2A Temporal Frequency

It was agreed that observations at least every 9 days were required, although this requirement should be solidly documented (at present, the 9 day requirement is mostly a matter of strong opinion).

2B Image Data Spatial Sampling

It is not clear what the sampling frequency should be. Reduction of current Landsat 1.4X oversampling could substantially reduce the data rate loading. Studies with simulated EOD data derived from aircraft data are recommended.

Resampling of image data to provide accurate geometric corrections is a well-established technology, and should be implemented in the central ground data processing system.

2C Conical vs Rectilinear Scanner

A basic user requirement is for rectilinear data, and this is sometimes thought to contradict the use of a conical scanner. However, conical scanner data can be processed to provide equivalent rectilinear data. The decision to use one scanner or the other should be based on overall system performance and cost, rather then on this single point.

Most of the panel members felt that the rectilinear scanner held an edge over the conical scanner. However, a minority believed the question to be not settled.

Comparative studies of overall system performance are needed, possibly using Skylab and Landsat data as a basis.

2D Thermal Band Resolution

A thermal IFOV of 3X the reflective IFOV has advantages for data processing. No data are available concerning the effect on classification accuracy of a different IFOV for thermal and reflective bands. Studies are recommended.

2E(a) Atmospheric Effects

The band near 0.92 micron should be modified to avoid water vapor absorption. Methods of correcting for atmospheric effects are lacking and research on the subject is recommended. Inclusion on the scanner of an ultraviolet band and an additional thermal band should be considered as "research" bands to estimate atmospheric effects.

2E(b) Sensor Canting

Canting of the Landsat scanner by 11.8° could obtain 2-day coverage (with 20% overlap of the data). Geometric distortions produced by the canting could be removed by ground processing. Canting is recommended, assuming the central ground data processor performs the necessary geometric corrections.

IA. SPECTRAL BAND SELECTION

1. Spectral bands with adequate signal/noise ratios, sensitivity, and dynamic range must be given priority over spatial resolution, since vegetation discrimination and condition monitoring will depend primarily on spectral differences among crops, forests, range vegetation and other cover types.

2. Recommended bands are:

0.45 - 0.52 μm
0.52 - 0.58
0.63 - 0.69
0.75 - 0.90
1.55 - 1.75
10.40 - 12.50

3. These bands are located in those parts of spectrum where maximum discrimination of vegetation types and conditions can be expected. In particular, the bands are narrower than the Landsat-1 and -2 bands to take maximum advantage of such features as the chlorophyll absorption region of green vegetation. The sharp rise in response between the visible and near-infrared was purposely avoided.

While fewer than six bands have often been shown to be sufficient for maximum classification accuracy, it is critical that as many different regions of the spectrum as possible be included. This is because the same three or four bands will not be optimum for any given time or place. From this standpoint, six bands is considered a minimum number.

Particular attention should be given to the possible addition of a 2-2.5 micron band, since preliminary studies of Skylab S-192 data indicate that this band shows high scene contrast, and may be especially useful for agricultural studies.

Consideration should be given for research purposes to a near-ultraviolet band (~ 0.38-0.44μm) which in aircraft scanner studies has been a good band for discrimination of cover types, in particular vegetation and bare soil. From satellite altitudes there would be strong atmospheric interference. This might minimize its utility for discrimination. On the other hand, it is conceiveable this could be turned into advantage by using this band to measure quantitatively atmospheric effects. This is definitely needed to work over large areas, i.e. signature extension. In order to keep the data load at a minimum, we recommend that this band be designed for the same spatial resolution as the thermal band.

Consideration should be given to having the capability to acquire thermal data at night, when thermal equilibrium has been reached. This would be for research purposes.

IB. SIGNAL-TO-NOISE RATIO AND DYNAMIC RANGE

Signal-to-Noise Requirements

The signal-to-noise ratio of the scanner should not exceed the signal-to-noise ratio of the scene. Scene noise has two parts; inherent noise, resulting from variations in surface reflectivity, and atmospheric noise, resulting from variations in atmospheric conditions. Data on these types of noise are limited. Work by ERIM showed that classification accuracy in one set of aircraft scanner data decreased when the noise-equivalent reflectance change ($NE_{\Delta}\rho$) was larger than 0.005. Data on atmospheric noise obtained by Duggin (see section on atmospheric effects) indicated average noise levels corresponding to a $NE_{\Delta}\rho$ of about 0.007 (for a typical agricultural scene in Landsat band 4). It can be concluded that a scanner $NE_{\Delta}\rho$ of 0.005 is probably sufficient, but further work is needed establish if this value is necessary. The dynamic range calculations outlined below are based on a requirement of 0.005 for $NE_{\Delta}\rho$.

Dynamic Range

Consider the energy reaching the radiometer.* This energy consists of 3 components.

a. Solar energy which is attenuated by the atmosphere before it reaches the ground is reflected by the ground and attenuated again by the atmosphere before it reaches the radiometer.

b. Solar energy which is singly or multiply scattered by the atmosphere to the radiometer, but not reflected by the surface.

c. Energy scattered into the line of sight which has been reflected by the ground outside the field of view.

It is the energy described in a. which we have to determine with the required accuracy.

---

*This description follows G.N. Plass and G.W. Kattawer, App. Optics 7, 1129 (1968)

If we assume that the required $NE_{\Delta}\rho$ on the ground is .005, i.e., that a change of ground reflectivity of .005 causes a 1 bit change in the system output, we can calculate the total dynamic range required for the system.

The change in ground radiance depends on two variables: Wavelength and Sun angle.

Figs. 1, 2, and 3 show the variation in ground radiance of .005 at a fixed sun angle. Shown on the same graph is also the total radiance seen by the radiometer for different average ground reflectance.

Since the lower curve defines the radiance change (above the atmosphere) for a .005 change in scene radiance and the top curves determine the maximum radiance seen by the radiometer, the dynamic range can be easily calculated.

The maximum radiance and, therefore, average ground albedo which can be handled by a 7 bit and 8 bit system is also shown on that figure.

Thus, as can be seen an 8 bit system is sufficient though marginal for 20° sun angle, for wavelengths greater than .5 micron, but only at a constant sun angle. Because as the sun angle changes, the radiance level representing a reflectivity change of .005 also changes. This effect is illustrated in figures 4, 5 and 6. Thus, to determine the total range capability required one has to consider the radiance change representing a $\Delta \rho$ of .005 at a 20° sun angle (or other value determined by operational latitude constraints) and the maximum radiance at a sun angle of 75° (11 o'clock).

Since the problem is more severe for wavelengths shorter than .7 micron and since the reflectivity of vegetation decreases at the shorter wavelength, the dynamic range was calculated for a typical vegetation spectrum. Results of these calculations are shown in Figure 6.

Since the low reflectivity of vegetation in the .5 to .75 micron range greatly reduces the total dynamic range required (9 bits), calculations were carried out for other ground materials. The results are shown in Figure 7.

Figure 8 is a summary of dynamic range requirements for various materials found on the ground. However, these calculations do not consider calibration and radiometric source errors.

Since 9 bits are required to cover vegetation and since there is no margin in a 9 bit system, it is recommended that a 10 bit system is developed for the S/C and that the significant 8 bits for data transmission be selected based on prior knowledge of the orbital parameters.

In summary, 8 bits are sufficient to cover the dynamic range at any one specified sun angle; however, for a satellite which collects data at varying latitudes and, therefore, varying sun angles, a 10bit system is required. Since the variation is slow, it will be possible to transmit two most significant bits only once per frame, thus causing no appreciable increase in the data transmission.

FIGURE CAPTIONS

Figure 1 - Spectral radiance for various scene albedos, and the spectral radiance change for 0.005 reflectance change in the IFOV. Solar elevation = 75 degrees.

Figure 2 - Same as Figure 1 except solar elevation = 45 degrees.

Figure 3 - Same as Figures 1 and 2 except solar elevation = 20 degrees.

Figure 4 - Spectral radiance vs. solar elevation for various scene albedos, and the spectral radiance change for 0.005 reflectance change in the IFOV. Wavelength = 0.4μm.

Figure 5 - Same as Figure 4 except λ = 0.7μm.

Figure 6 - Typical vegetation spectrum, and the dynamic range required to achieve $NE\Delta\rho = 0.005$ for sun elevations between 20 and 75 degrees. The dynamic range curve is equal to the ratio of the two solid curves.

Figure 7 - Typical spectra for arid scenes and the corresponding required dynamic range for $NE\Delta\rho = 0.005$ and solar elevations between 20 and 75 degrees.

Figure 8 - Summary of dynamic range calculations for vegetal and arid scenes.

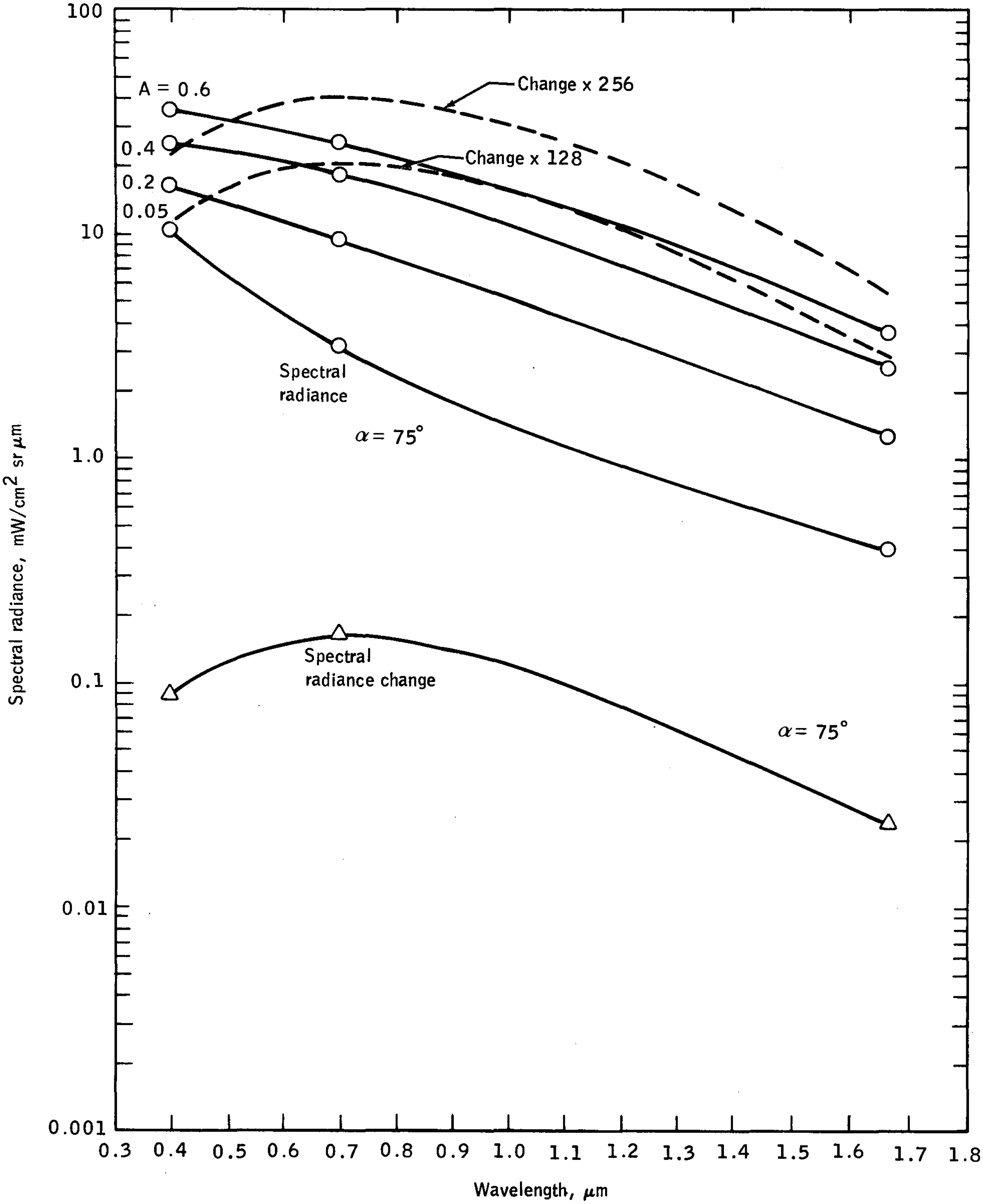

100
10
1.0
0.1
0.01
0.001
Spectral radiance, mW/cm^2 sr µm
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
Wavelength, µm
A = 0.6
0.4
0.2
0.05
Change x 256
Change x 128
Spectral radiance
α = 75°
Spectral radiance change
α = 75°

FIGURE 1

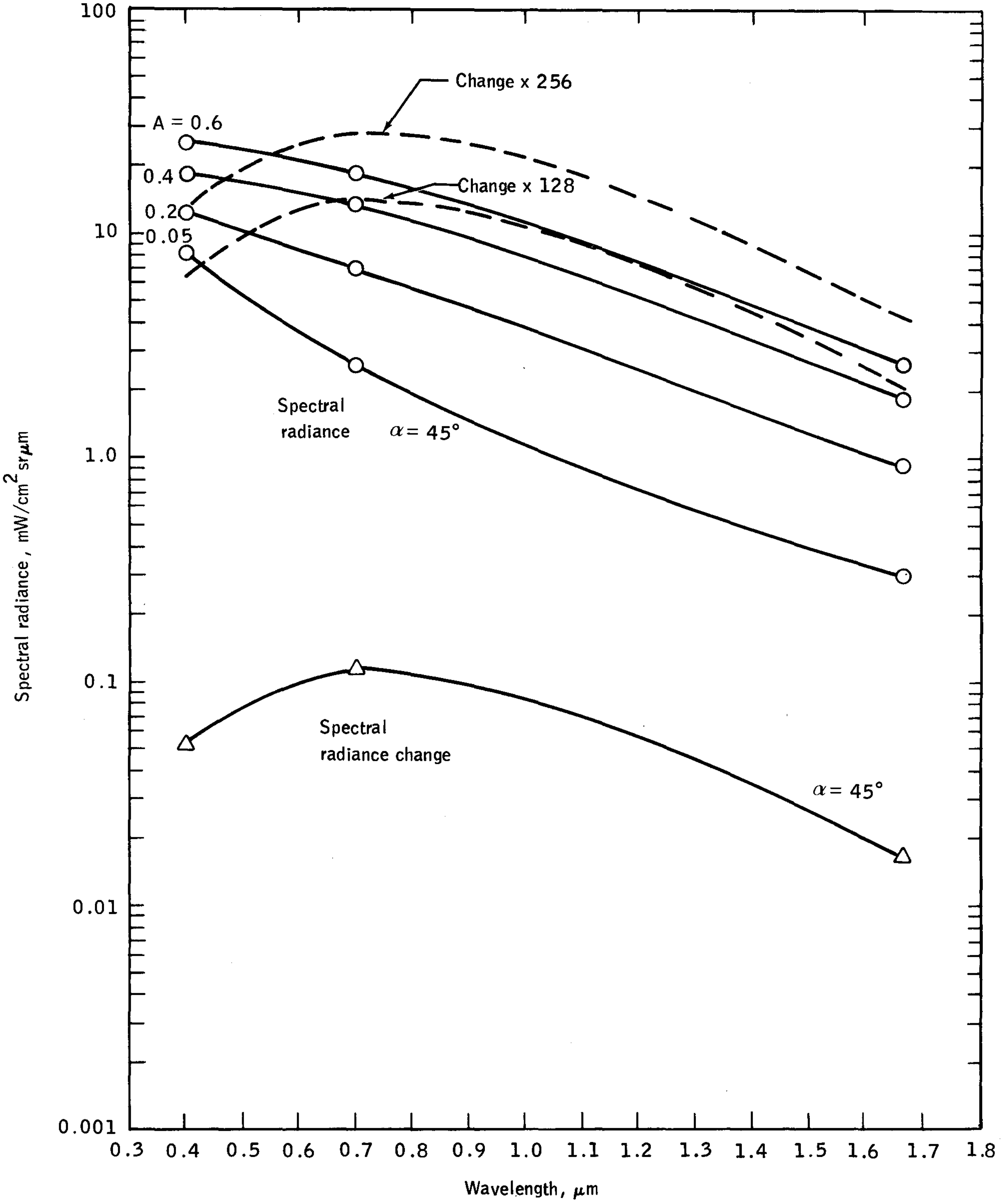

100
10
1.0
0.1
0.01
0.001
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
Wavelength, μm
Spectral radiance, mW/cm2 sr μm
Change x 256
Change x 128
A = 0.6
0.4
0.2
0.05
Spectral
radiance
α = 45°
Spectral
radiance change
α = 45°

FIGURE 2

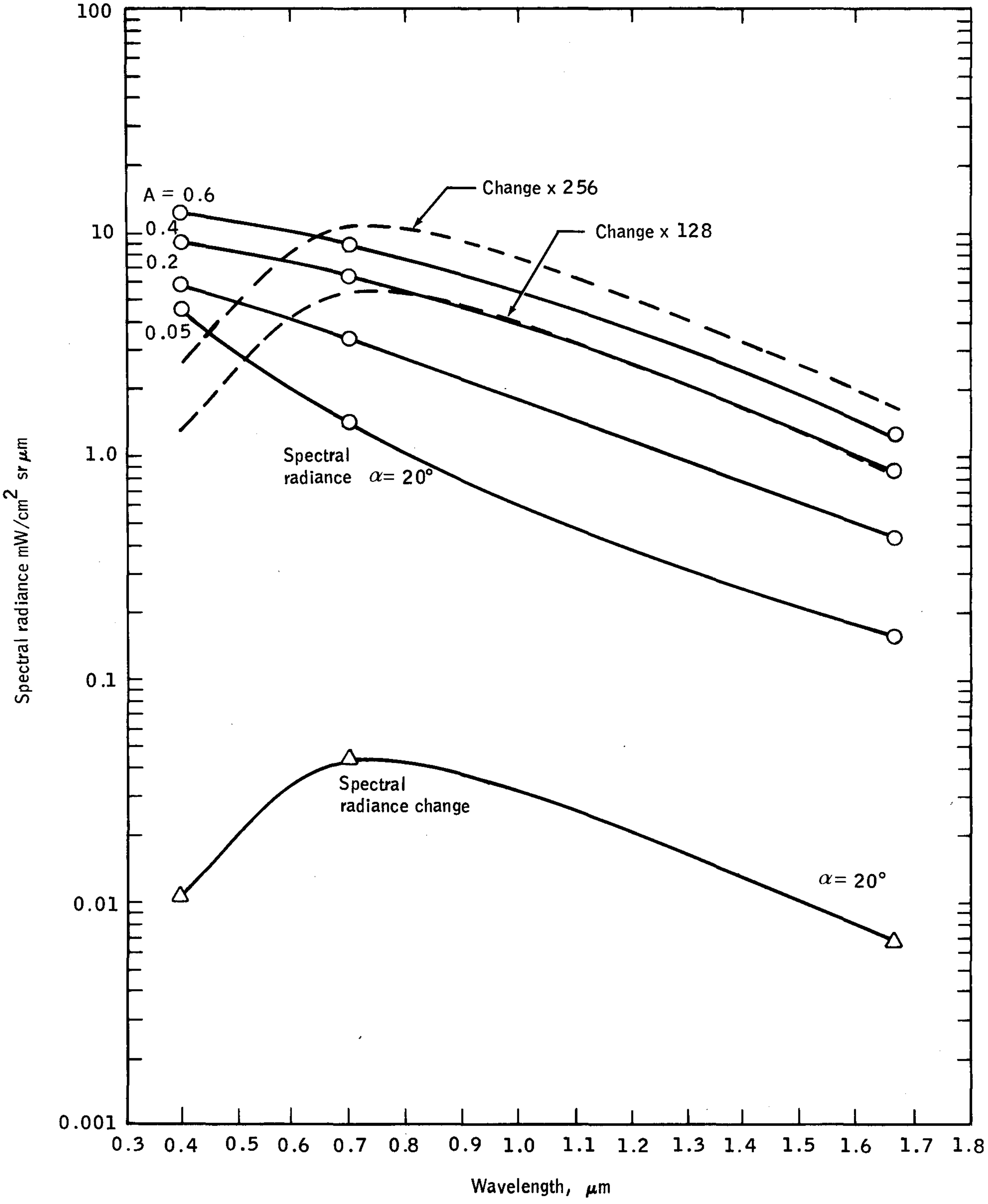

100
10
1.0
0.1
0.01
0.001
Spectral radiance mW/cm^2 sr μm
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
Wavelength, μm
A = 0.6
0.4
0.2
0.05
Change x 256
Change x 128
Spectral radiance α= 20°
Spectral radiance change
α= 20°

FIGURE 3

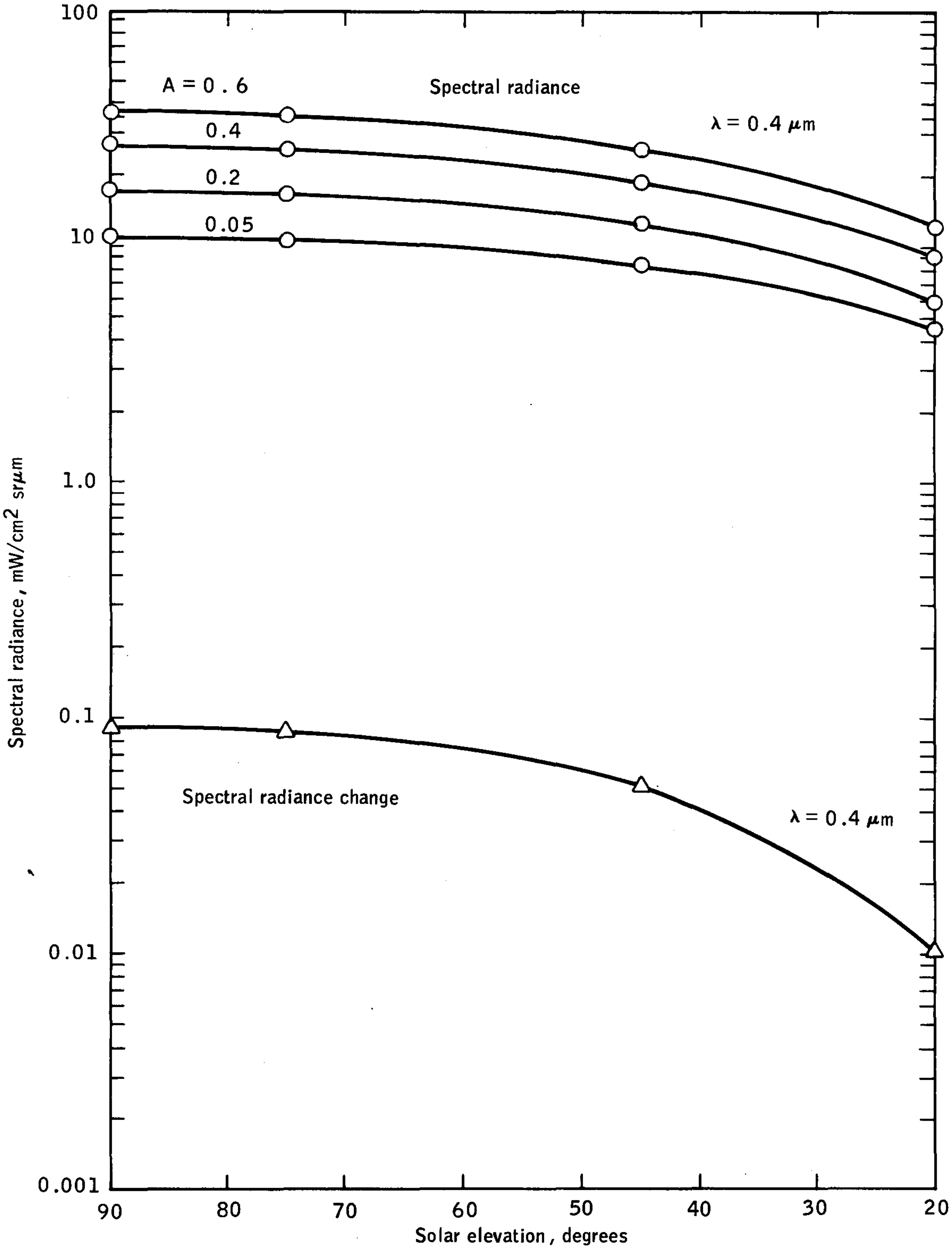

100
10
1.0
0.1
0.01
0.001
A = 0 . 6
0.4
0.2
0.05
Spectral radiance
λ = 0.4 μm
Spectral radiance change
λ = 0.4 μm
90
80
70
60
50
40
30
20
Solar elevation, degrees
Spectral radiance, mW/cm2 srμm

FIGURE 4

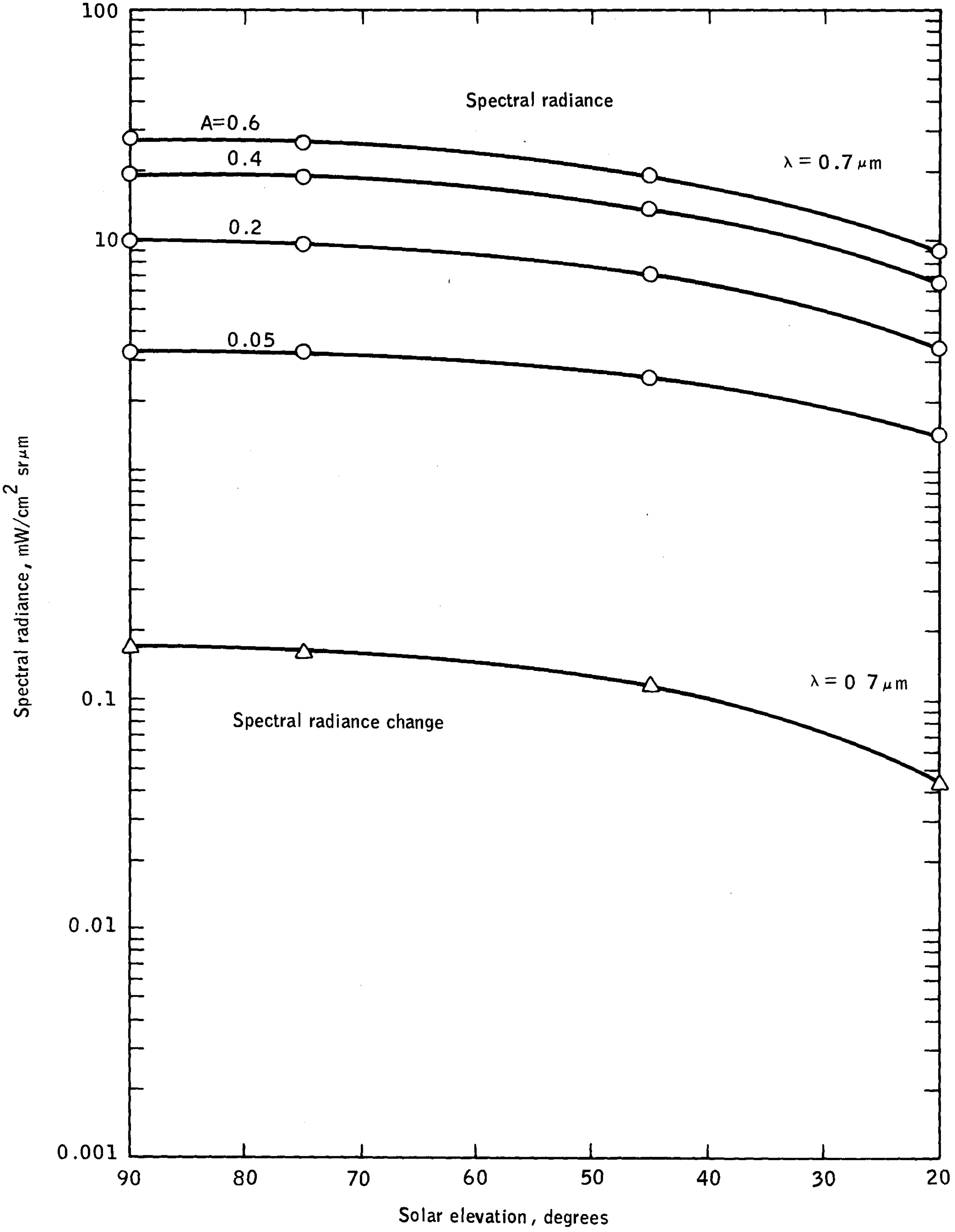
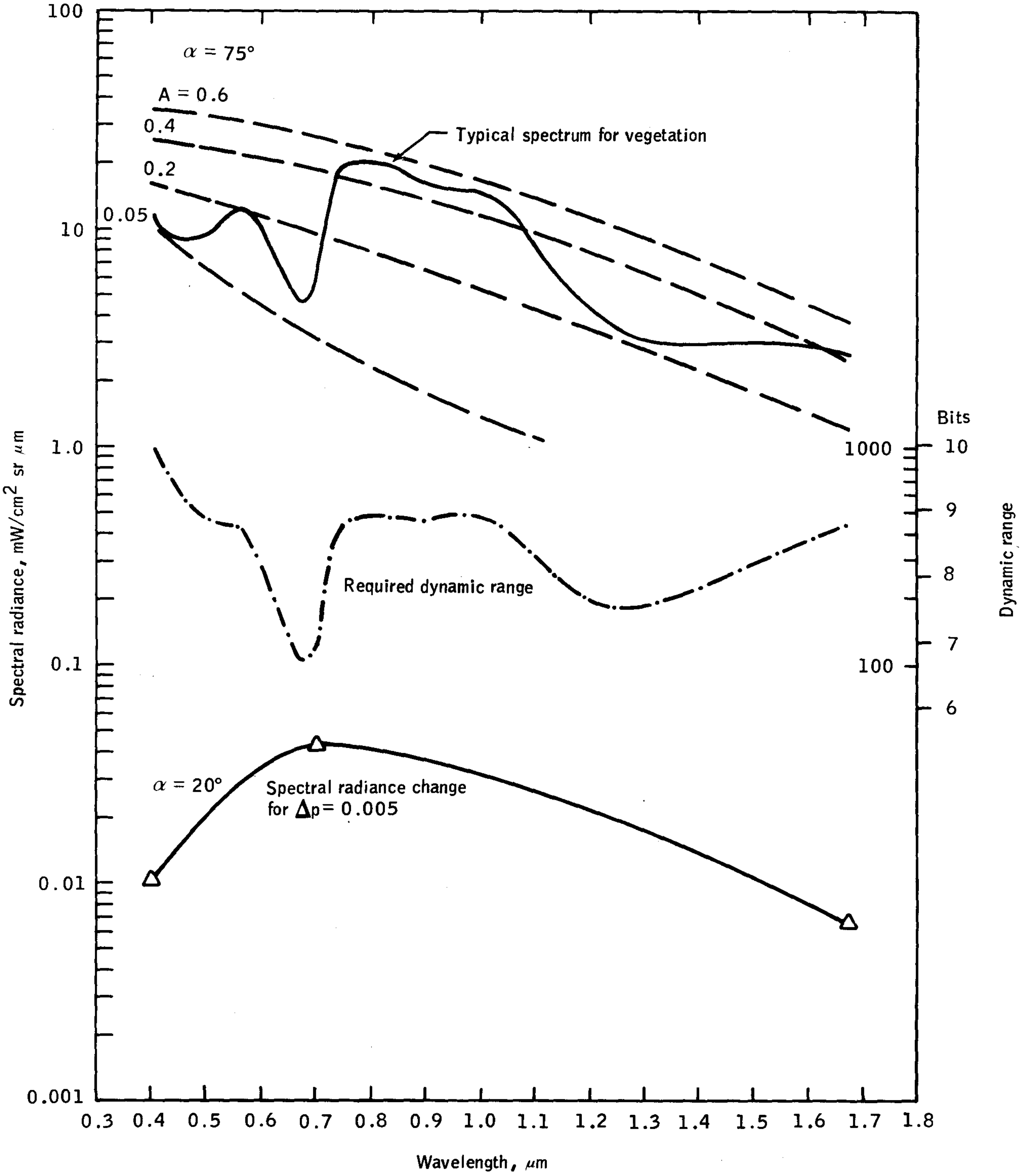

Spectral radiance
A=0.6
0.4
0.2
0.05
λ = 0.7 μm
λ = 0 7 μm
Spectral radiance change
Spectral radiance, mW/cm^2 sr μm
100
10
0.1
0.01
0.001
90
80
70
60
50
40
30
20
Solar elevation, degrees

FIGURE 5



α = 75°
A = 0.6
0.4
0.2
0.05
Typical spectrum for vegetation
Required dynamic range
α = 20°
Spectral radiance change for Δp = 0.005
Spectral radiance, mW/cm² sr μm
100
10
1.0
0.1
0.01
0.001
Bits
10
9
8
7
6
1000
100
Dynamic range
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
Wavelength, μm

FIGURE 6

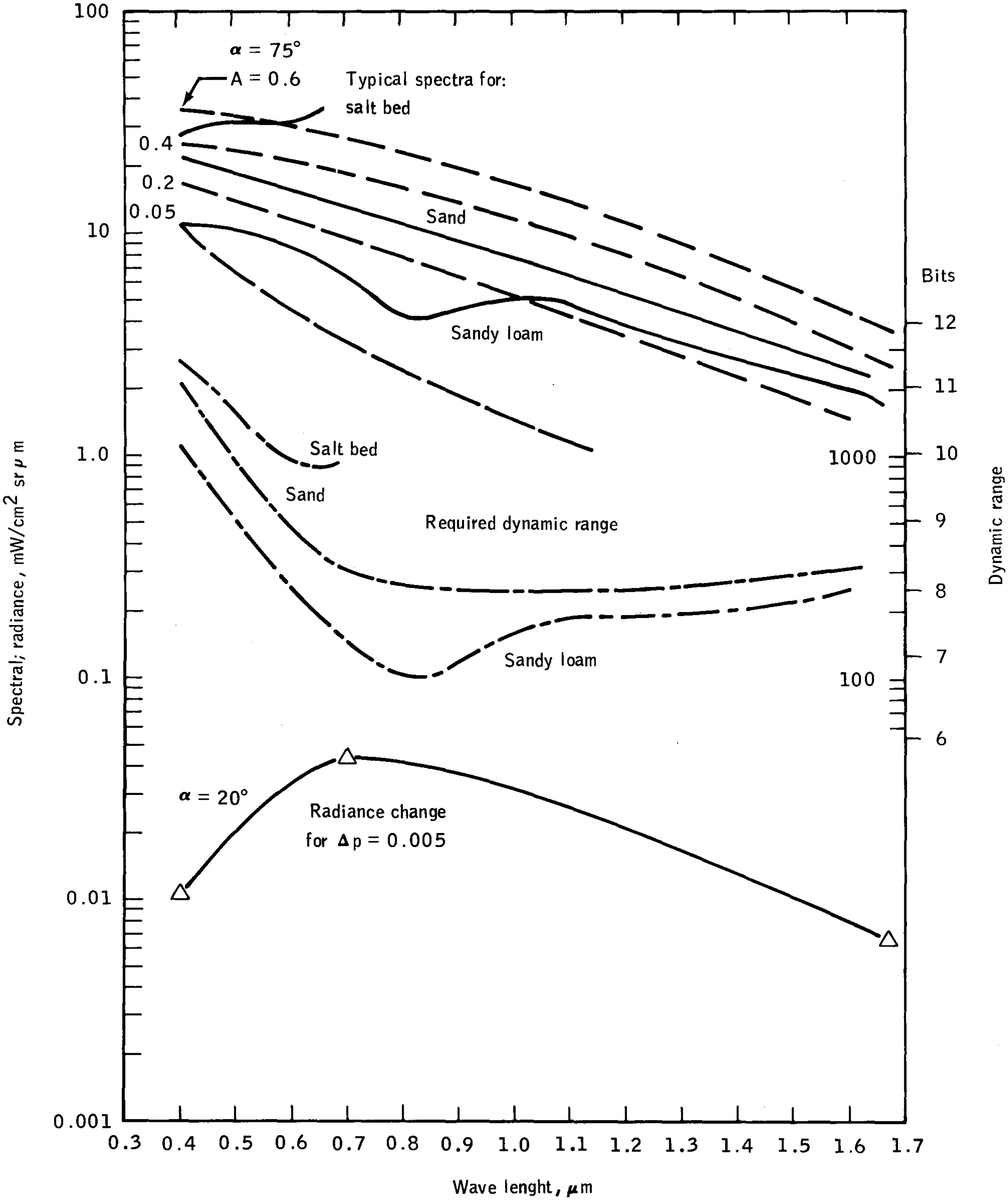

100
10
1.0
0.1
0.01
0.001
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
Wave lenght, μm
Spectral; radiance, mW/cm² sr μ m
α = 75°
A = 0.6
Typical spectra for:
salt bed
0.4
0.2
0.05
Sand
Sandy loam
Salt bed
Sand
Required dynamic range
Sandy loam
α = 20°
Radiance change
for Δp = 0.005
Bits
12
11
10
9
8
7
6
1000
100
Dynamic range

FIGURE 7

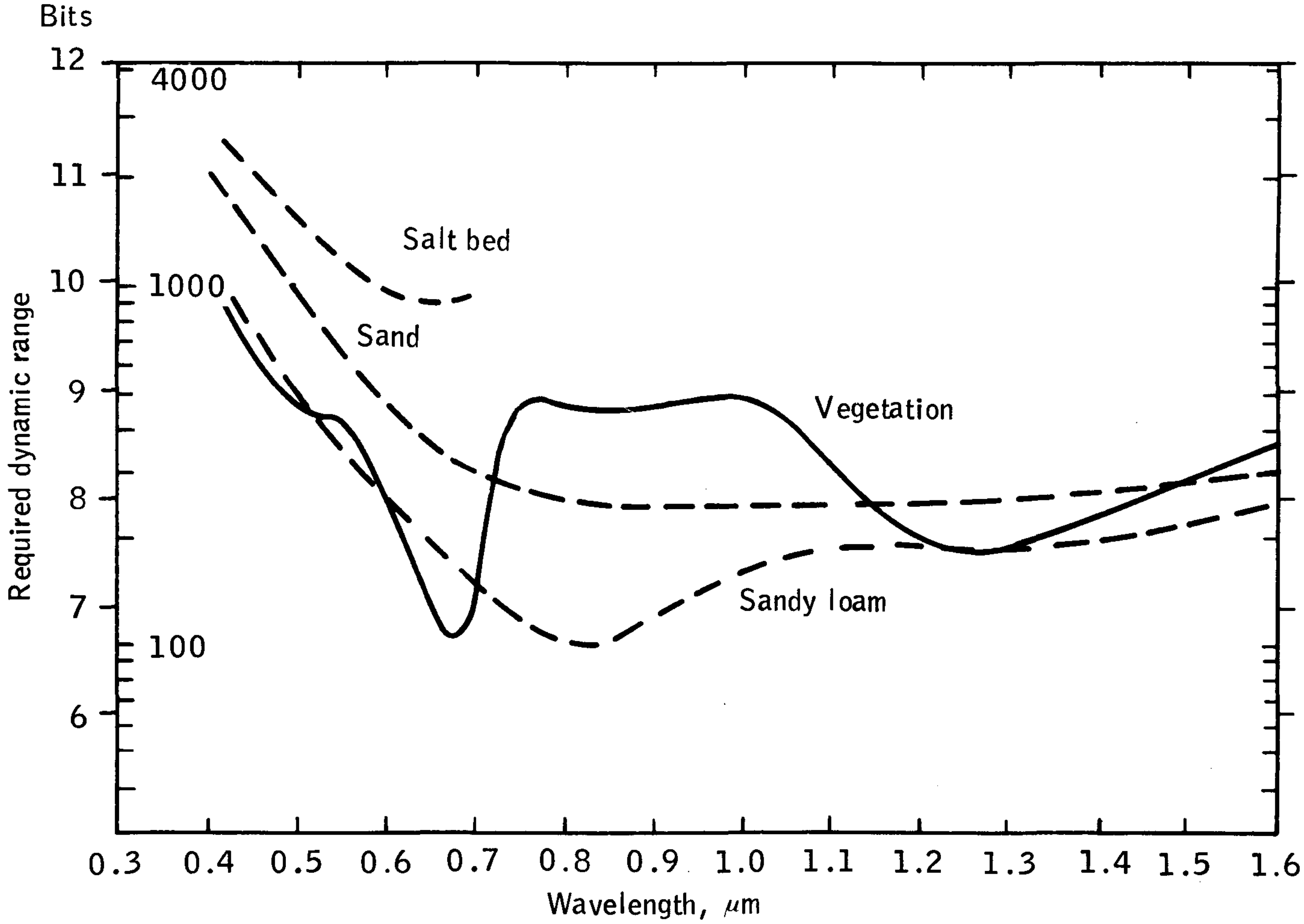

Bits
12
11
10
9
8
7
6
4000
1000
100
Required dynamic range
Salt bed
Sand
Vegetation
Sandy loam
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
Wavelength, μm

FIGURE 8

Dynamic Range and Quantization Noise

There seems to be some confusion in relating quantization noise to scanner noise. In order to combine the two types, it is necessary to recognize that scanner S/N will be measured in terms of peak-to-peak signal relative to r ms noise. The equivalent statement for quantizing in n-bits is

$$\left(\frac{S}{N}\right)_{QUANT} = 2^n\sqrt{12.}$$

Because no encoder is error free it is convenient to reflect the error in n, and arrive at the examples shown in Table 1.

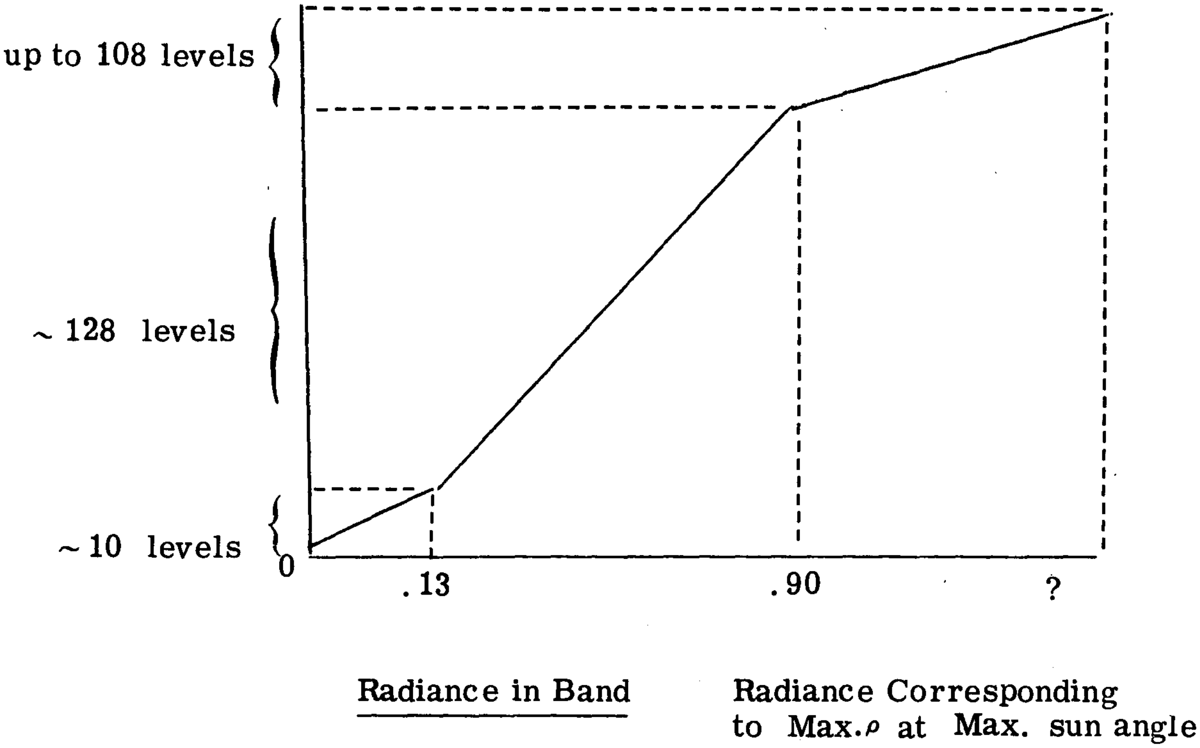
Number of Bits	Equivalent Bits	$\frac{\text{Signal}}{\text{Noise}} = \frac{\text{pk-pk voltage}}{\text{rms voltage}} = 2^n\sqrt{12}$
6	5.6	168
7	6.6	336
8	7.5	627
9	8.5	1254
10	9.5	2508

If we now compare this with the noise values implied in meeting the NE$\Delta\rho$ of .005 we can arrive at the following requirements: (The following suggests a technique and should be refined using a better survey of stmospheric models).

Consider the ERIM band (.74-.80$_{\mu}$m) because this is most demanding of the encoding levels. At the lowest radiance (.13 mw ster^{-1} cm^{-2} in band) the scanner NE$\Delta\rho$ might be .0035 and the quanization NE must be the same to preserve the required .005 on an rms basis

When this value is translated to NE$\Delta\rho$ using the Rogers and Peacock data (e.g.) we have a value of .0041 for each which implies a signal to noise of .13/.0041 or 32. If we now extend this to the maximum stated value of 0.90 (15.08 L times .06 $_{\mu}$m) we find a maximum signal to noise of 223.

Examining the table we find that 7 bits would cover the range which can be regarded as the "precision range." It is now possible to devote another bit (8 bits total) to the rest of the range by incorporating different gain levels, thus



If the precision range proves not to be any more demanding than in the example shown, it is probably desirable to eliminate the lower breakpoint and continue straight to zero; however, consideration could be given to setting the d.c. restore level at a radiance calculated to correspond to the best atmospheric model minimum. The range of reflectivities suggested tentatively for inclusion in the dynamic range or all sun conditions as shown in Table 2.

	Precision Range		Complete Range
	Min	Max	Total
Band 1	.02	.25	50
2	.02	.60(?)	100
3	.02	.78	100
4	.02	.90	100

Table 2. Reflectivities for bands below 1 micro-meter.

IC. SPATIAL RESOLUTION

The required spatial resolution is a function of the specific application. For crop inventory, the major application is determination of acreage. Once the minimum field size is decided upon, the resolution can be specified approximately.

Guidelines to the approximate number of resolution elements required per field can be obtained from the CITARS study, and from procedures which are common practice in field identification by manual interpretation of false color imagery.

The CITARS experiment dealt with acreage determination of corn and soybeans in the Midwest.

The average field size in the counties of Indiana and Illinois varied from 15 to 40 acres. With approximately one resolution cell to the acre (Landsat I resolution), crop proportion estimates for areas with fields of 35 to 40 acres were classified with substantially less error than fields of 15 to 20 acres (see the attached Fig. 1). These results indicate that the number of resolution cells per field should be ≥ 40.

This provides about 15 non-boundary interior resolution cells. For analyst interpretation of imagery, we would like to have 30 non-boundary interior resolution cells for the smallest field size of interest. The following calculation therefore ensues:

Let n be the number of acres in the smallest field we wish to consider. Let c be the number of resolution cells per acre. Then, $nc-4\sqrt{nc}$ is the number of resolution cells in the interior (non-boundary resolution cells) of square field of n acres. We want this to be at least 30 resolution cells. This implies that nc = 60; the number of resolution cells per field should be about 60. The required resolution can now be determined, if the smallest field to be analyzed is defined.

CITARS

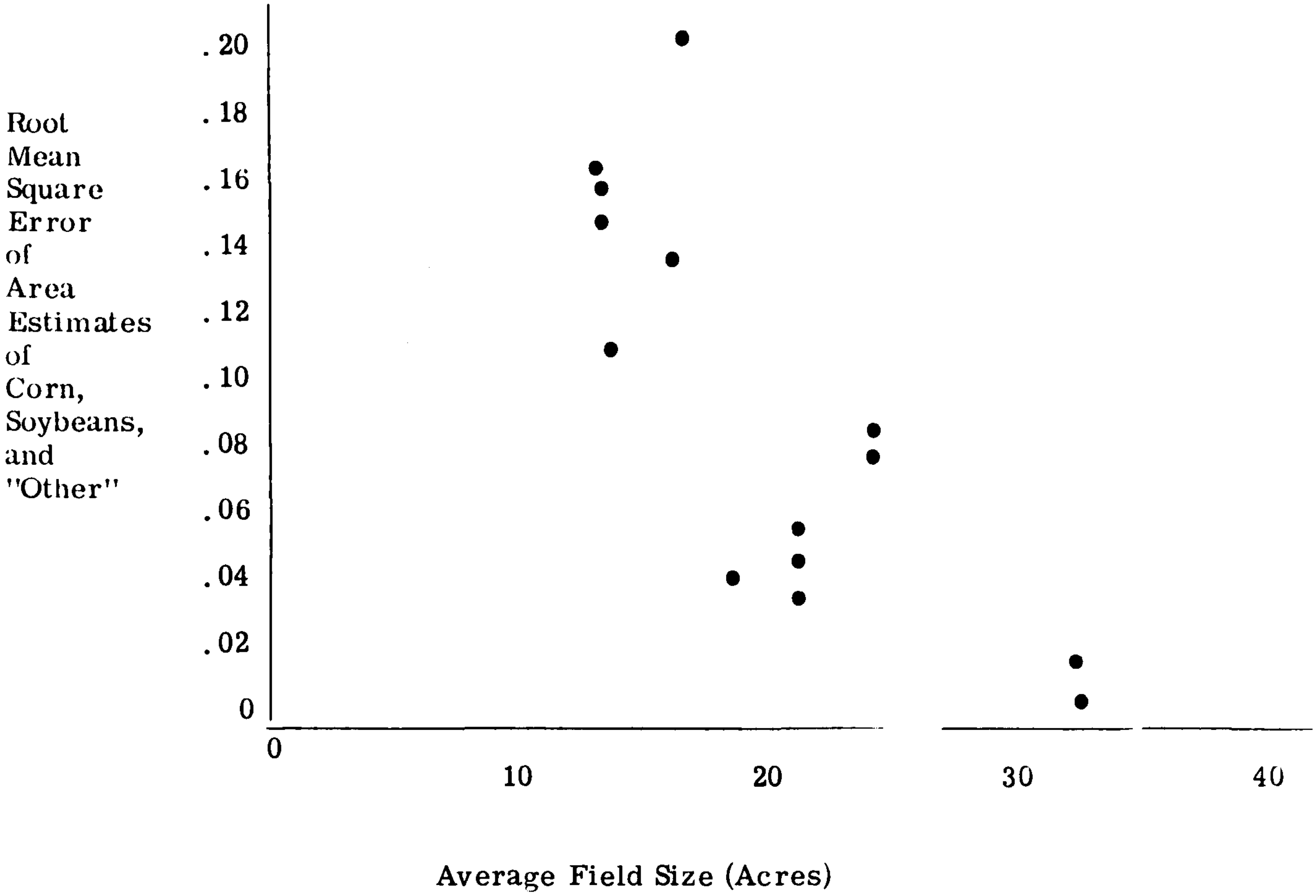
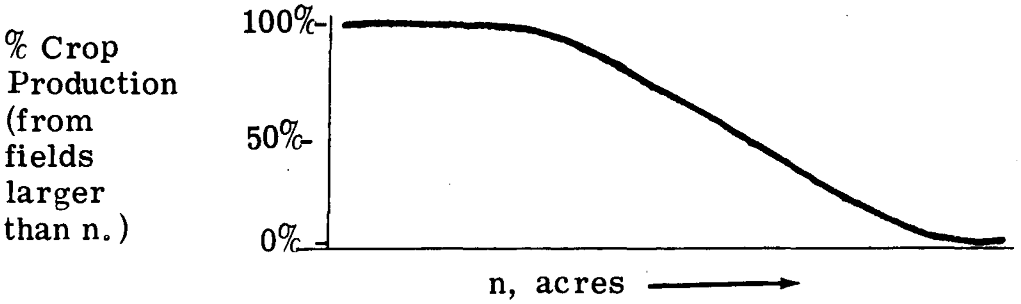


Figure 1C-1

To determine how many acres in the smallest field, we require a curve showing the percentage of crop production from field size larger than n acres versus n acres.



We choose the percentage at which we wish to cut off the acreage determination and then determine n.

We do not have crop production percentage curves. Using data on wheat field sizes shown in the Table 1, our guess is that a 20 acre smallest field size is about right. This implies a 39 meter IFOV. resolution.

Some advantages of the 39 meter IFOV are:

a. Either a 2x2 average or selection of every other line and column transforms it to a Landsat format for easy use by groups who have established Landsat processing capabilities.

b. Use of a 39 meter IFOV instead of a 30 meter IFOV reduces the number of bits per picture by almost half, so that a second satellite can be used to provide 9-day coverage and keep the total system bit throughput rate about the same.

Table IC -1

FIELD SIZE DATA

COUNTRY	AVERAGE WHEAT FIELD SIZE, ACRES	RANGE OF FIELD SIZES, ACRES
ARGENTINA	75	50-300
BRAZIL	50	FAIRLY UNIFORM
INDIA	1/8	FEW LARGE FIELDS
AUSTRALIA	500	200-5000
RUSSIA	50 (WESTERN)	-
	50,000 (EASTERN)	-
CHINA	2 (NORTHERN)	-
	60 (MANCHURIA)	20 - 100
CANADA	160	50 - 640
U.S. (GT. PLAINS)	80	50 - 160

ID. IMAGE DATA GEOMETRIC ACCURACY

From the point of view of the user, geometric accuracy should be specified in terms of what he needs in order to accomplish his objectives. These needs usually relate to location of the image data set relative to a map, the ability to locate other sensor data within a scene relative to known locations, accurate image geometry for area computation, and the degree of geometric registration that exists between two or more scenes acquired and processed at different times. The first parameter will be defined as absolute geometric accuracy, the second and third can be specified and controlled by an internal geometry accuracy specification, and the last can be specified by a relative or temporal accuracy specification.

Table 1.D-1 identifies the highest level of performance requirements defined as those needed for performing crop classification. It is noted that functional picture element accuracies were specified in order to accurately locate crop areas and training regions, and to compute crop acreages. Further, since advanced multispectral classification techniques utilize two or more scenes of the same ground area, each scene should be in coincidence with the other by about 1/2 picture element.

Table 1.D-1 also shows what is achievable by the use of advanced digital image processing techniques, based upon both Landsat data processing experiments and analytic results, and Thematic Mapper accuracy studies. It is obvious that requirements can be satisfied provided that unknown sensor errors are within the error budget.

Table 1.D-2 identifies a set of sensor parameters that influence the sensor internal geometric distortions that cannot, generally, be eliminated. These distortions should be within the error budget given, in order to assure that the performance of Table 1.D-1 can be achieved.

Table 1. D-1 Geometric Accuracy Performance - Corrected Data

	Panel 2 Needed	Achievable
Absolute Accuracy	0. 5 pixel	0. 5 pixel
Internal Consistence	0. 5 "	0. 4 "
Temporal (Relative) Accuracy	0. 5 "	0. 5 "

Table 1. D-2 Sensor Geometric Accuracy Error Budget

Start of Scan Stability	3 μ rad
Along Scan Positioned Accuracy	4 μ rad
Across Scan Non-linearity	4 μ rad
Detector Position	
Actual Placement	0. 1 IFOV
Knowledge of Placement	0. 1 IFOV

References:

1. R. Bernstein, "Scene Correction (Precision Processing) of ERTS Sensor Data Using Digital Image Processing Techniques." Third Earth Resources Tech Satellite - 1 Symp Vol I, Sect. B, Dec 10-14. 1973 NASA SP-351.
2. R. Bernstein, Multi-Digital Processing of ERTS Images, Final Report, NASA Contract NAS 5-21716, April 1975.
3. Earth Observations Satellite Systems Definition Study, Final Report, G. Electric, 15 Oct 1974.

2A. TEMPORAL FREQUENCY OF OBSERVATIONS

Observations are needed more often than once every 18 days for many vegetation monitoring/agricultural applications. As a result a seven- or a nine-day capability is much preferred. Variations wherein one satellite would follow the other by one day, two days, three days, and six days, and other intervals were discussed, but it was judged that the equal time intervals of about 9 days would serve most interests best. Documentation of this requirement is needed, but is generally lacking.

It was noted that the time between heading and harvest of wheat is approximately one month. Many industries have need for information of progress of harvest, e.g. grain exporters as Cargill and Cook need the information in order to plan efficiently for transportation to shipping ports. It was further noted that cloud cover interference typically causes the actual observation frequency to be less than the satellite revisit cycle; i.e., instead of a nine day frequency in the Midwest, an 18 day coverage frequency would actually result. Therefore, in order to monitor harvesting and phenological events associated with major crops, and rangeland grazing and management, a two-satellite, nine-day configuration is recommended for the Thematic Mapper. A seven-day repeat cycle has advantages for scheduling of ground data analysis, as well as giving 20% more frequent coverage. It is recommended that the seven-day repeat cycle be studied as a possible alternative to the nine-day repeat cycle.

2B. IMAGE DATA SPATIAL SAMPLING SCHEMES

Spatial sampling relates to both the size of the IFOV and the frequency of sampling of IFOV detector output. Fig. 2B-1 indicates a typical cross-track (along-scan) over-sampling condition. It is noted that in this example, the IFOV's overlap in the scan direction by a factor $\frac{79}{57} = 1.4$, and by a factor of 1 in the along-track (cross scan) direction. Generally, oversampling is implemented in order to maintain the same Modulation Transfer Function (MTF) in the along-scan direction as in the cross-scan direction, and to compensate for the presampling filter. It is apparent that the amount of data produced is directly proportional to the amount of oversampling.

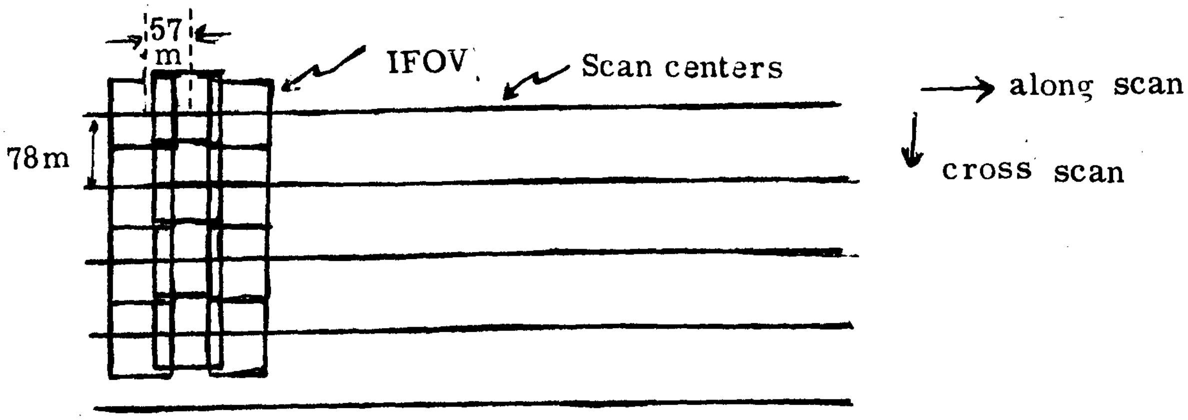


Fig 2.B-1 Sensor Sampling Convention

For example, if a 30m IFOV is considered, then for a 185 km along-track scan and 185 km cross-track height, each band would consist of 53.5 x 10^6 bytes of data for a 1.4:1 resampling scheme, and only 38 x 10^6 bytes of data for a 1:1 resampling scheme. This has obvious impacts: the communications link, ground storage, and ground information extraction operation could be reduced by about 29% if a 1:1 resampling scheme for crop inventory were found to be adequate. Although a slight reduction in horizontal resolution will result, this may be more than off-set by the benefit of lower data processing and reduced bandwidth requirements.

The selection of training fields, and the definition of field edges in the along-track direction may be affected. It is not known at this time the extent of the affect.

Research Recommendation on Sampling Rate

Aircraft data could and should be used to predict the effect of various IFOV's and sampling shcemes by digital simulation of low resolution orbital IFOV's from high resolution aircraft IFOV's for various oversampling conditions and field sizes. A controlled experiment could be conducted that would provide some insight into the degree of benefit of oversampling of the data, or alternatively, the decrease based on multispectral classification accuracy results.

Resampling of Image Data

Another aspect of spatial sampling schemes relates to resampling of the input image data to generate the output image data. Three resampling schemes have been analyzed in the past. They are nearest neighbor, bi-linear interpolation, and cubic convolution. They are progressively computationally more sophisticated and expensive. Nearest neighbor uses 1 input point, bi-linear interpolation uses 4 weighted input points, and cubic convolution uses 16 weighted input points.

These resampling schemes have been implemented experimentally and applied to Landsat scanner data. The results show that very substantial improvements in image quality can be achieved from cubic convolution resampling.

It appears that a resampling filter of cubic convolution or higher order is probably warranted at the central ground data processing station, in particular, if sensor detector placement and sampling effects cause high frequency saw tooth and registration problems. Since special-purpose high speed digital hardware can be used to implement the resampling algorithm, the computational cost should not be an important consideration. Growth to a higher order function, such as in 6x6 array should be considered.

Background: Rationale for Sampling Rate Used in Landsat Scanner

The sampling rate corresponding to 1.4 samples for each IFOV dwell time was selected to produce a system MTF which is essentially the same for the horizontal and vertical direction. This system used an electrical filter with an amplitude of 0.7 at the spatial frequency of $(2\ \text{IFOV})^{-1}$. The sampler was a sample and hold variety which permits aliasing terms to appear. If a rate of 1 sample per IFOV were used, the equivalent MTF at $(2\ \text{IFOV})^{-1}$ would be 0.64 whereas the 1.4 rate used gives 0.81. This advantage, combined with the extra safety against aliasing and the availability of data link capability, led to the decision to use the more conservative level.

Subsequently it was determined that using an integrate and dump type of sampling offers several advantages. First, the sampler serves as a filter so that the total MTF can be maintained at 0.64 with only 1 sample per dwell time (i.e. the effect of an electrical filter 0.70 times the 1.4 sampling of 0.8 is replaced by a single 1.0 sampling). Secondly, aliasing is eliminated if the integration for each IFOV is exactly continuous.

Thirdly, the data rate is reduced according to the plots shown on Figure 2B-2. This method of sampling will necessarily be used if charge coupled detectors (CCD) detectors become available and would probably be worth incorporating even if conventional detectors are used. The second point of integrating contiguity offers some problem in present day CCD since the collecting areas have inactive strips between.

References:

1. R. Bernstein, "Resampling Techniques and Implementation, - Digital Image Processing Workshop, USDI Geol. Survey, EROS Data Center, Souix Falls, S. Dak., 20 Nov 1974.

2. R. Bernstein, "Digital Image Processing Earth Observations Sensors," Submitted to IBM Journal of Research and Development.

3. Final Report, TRW, "Evaluation of Digital Correction Techniques for ERTS Images," SS. Rifman, D. M. McKinnon, March 1974. NASA Contract NAS5-21814.

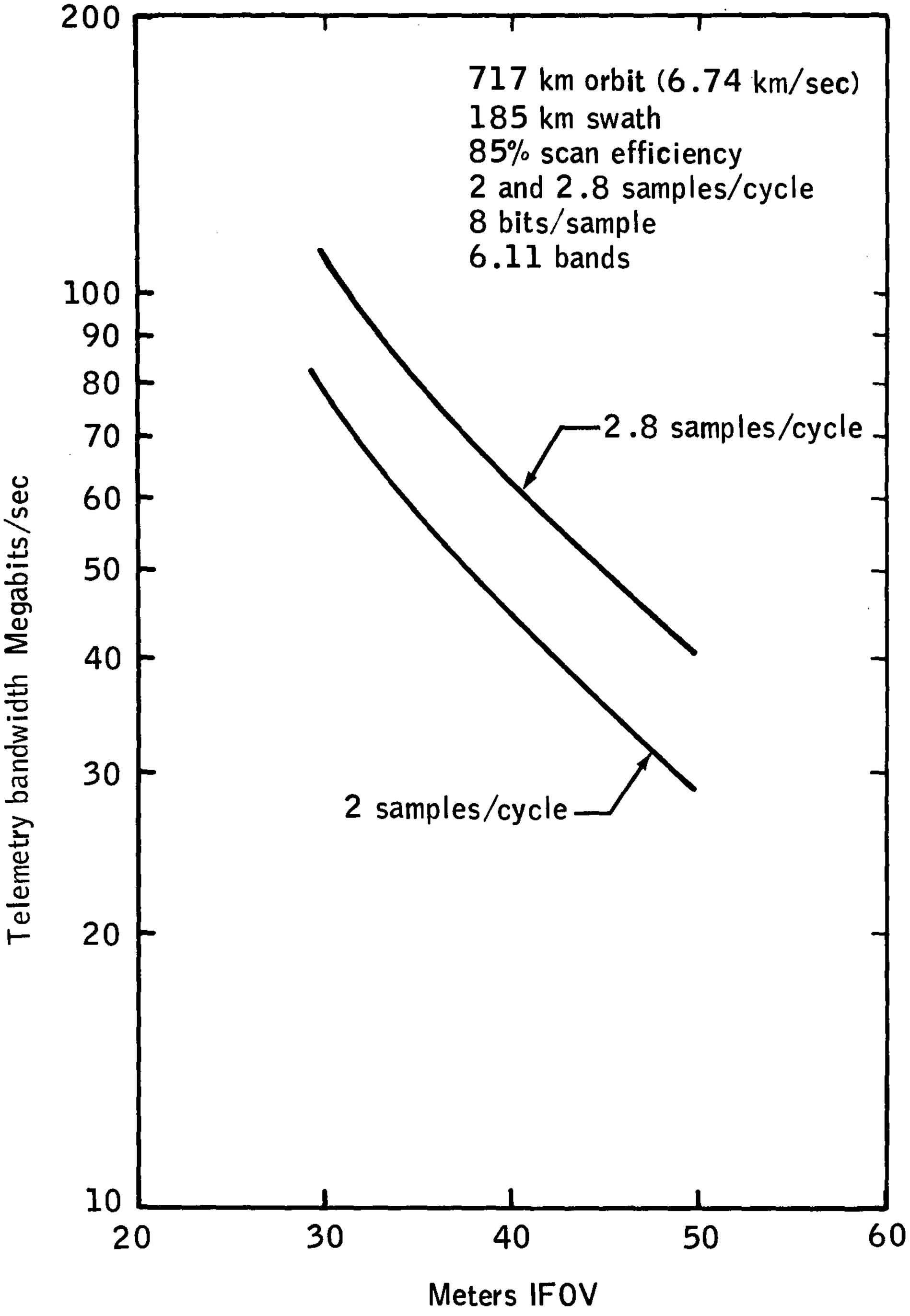


FIGURE 2B-2. Telemetry bandwidth vs IFOV

2C. CONICAL VS RECTILINEAR SCAN

It is sometimes stated that the rectilinear scanner is preferable because users require rectilinear data. However, there is no evidence to indicate a significant difference in data quality between conical scan and rectilinear scan data after geometric correction and resampling. A decision to use one scanner or the other should be based on overall system performance and cost rather than on this point alone. Factors which should be considered are:

a. Rectilinear scan data requires less correction and is therefore easier to process on the ground. Conical scan data must be converted to rectilinear format for user products. Ground data processing systems may require additional memory to effect this conversion (Reference 1).

b. Although the conical scanner may have a constant path length and therefore a possible constant atmospheric effect on radiometric accuracy and a constant size IFOV, at satellite altitudes and total scan angle for conical scanners, there advantages are small. (Ref. 2).

c. The conical scanner views the terrain at varying sun angle and aspect with respect to crop rows and other regular terrain patterns. This may introduce data variance which should be further evaluated.

d. Terrain reflief effects are less on the average for the rectilinear scanner.

e. For small, local read out stations (if planned), rectilinear scan data would avoid development of conical scan data output devices. However, if the central processing facility provides corrected data over telephone lines, this problem could be avoided.

f. The conical scanner is mechanically simpler than the rectilinear scanner, and may therefore exhibit better reliability.

Skylab S-192 and Landsat data could be comparatively analyzed to answer some of the considerations.

References:

1. D. H. Ebert, et al "Conical Scan Impact Study, Vol 1. General Central Data Processing Facility," Final Report, Bendix Aerospace Systems Division, NASA Contract No. NAS-5-21903, Sept 1973.

2. R. H. Rogers, "Investigation of Techniques for Correcting ERTS Data for Solar and Atmospheric Effects," Final Report, Bendix Aerospace Systems Division, NASA Contract NAS-5-21863.

2D. THERMAL BAND RESOLUTION

The incorporation of the thermal band as an important parameter in a vegetation classification system has been demonstrated in numerous classification studies (refs. 1, 2, and 3). The influence on the classification accuracy if the thermal channel IFOV is not the same as the IFOV of the other channels is not known. Hence, if instrument constraints limit the minimum IFOV of the thermal channel, it is felt that an IFOV of 3X that of the visible channels should be used. The use of the integer value three provides for convenient registration of the center of the thermal band on the other bands, in performing classification and overlaying images. To simplify data processing, registration of the thermal, and other bands should be preserved. For a thermal IFOV of 3X the other bands, each thermal band IFOV should correspond to a 3x3 group of nonthermal band IFOV's. Both the thermal IFOV and corresponding nonthermal band 3x3 groups should be sampled at the same time. If the nonthermal detector array scans N lines in a single sweep, the thermal detector array should be configured such that $\frac{N}{t}$ equals an integer, where t corresponds to the number of nonthermal band IFOV's per thermal band IFOV.

References:

1. F.J. Thomson, et al, "Multispectral Scanner Data Applications Evaluation," Volume I User Applications Study, NASA-JSC 09241, ERIM Report 102800-40-F, December 1974.

2. S. Viglione, Nelson, E., Goldsworthy, W., "Automatic Crop Classification; McDonnell Douglas Astronautics Company, (MDAC), 1972.

3. Nelson, E, Byrne, E, "Multispectral Imager and Vegetation Classification, MDAC, 1973.

2E(a). ATMOSPHERIC EFFECTS

Reflected sunlight received from the earth by an orbiting sensor has passed twice through the atmosphere. As a consequence, scattering and absorption by atmospheric haze and water vapor modifies the spectral characteristics of the reflected sunlight, and hence, the spectral signatures as measured by a multispectral scanner. Within a given air mass, corresponding roughly to a high-pressure or low-pressure region, haze and water vapor content may be expected to be relatively constant, with small-scale variations ("noise") superimposed on a mean value. This leads to two effects in computer classification of multispectral image data. One arises from differences of the mean value, and the other from the fluctuations around the mean.

In "signature extension", identified image data ("training" data) are used to classify or identify image data from a different place or time ("test" data). A difference in the mean atmospheric condition between the training and test data, can produce significant losses of classification accuracy in signature extension.

The other effect results from small-scale fluctuations in atmospheric conditions, which introduces a noise component into the image data.

ATMOSPHERIC EFFECTS ON SIGNATURE EXTENSION

When mean atmospheric conditions are different between test and training fields, significant losses of classification accuracy can occur. Two types of atmospheric effect are important; haze effects, due to aerosols (suspended particulate matter) and water vapor effects, in which light absorption by water vapor occurs.

Haze Effects

The importance of this effect was demonstrated in the CITARS experiment, where signature extension was attempted using Landsat-1 data collected over Indiana and Illinois during 1973-1974. Ground-based haze level measurements were made simultaneously with the Landsat-1 over-passes. It was found (ref. 1) that the classification accuracy for signature extension was negatively correlated with the difference of haze level between test and training fields. A large difference of haze level produced a low classification accuracy. The results are plotted in Fig. 1 where the classification accuracy (expressed as probability of correct classification per pixel) is plotted against the difference of haze level (expressed as optical depth) between training and test fields. ERIM SP1 in the figure refers to the classifier used, which was a linear decision rule developed by ERIM. Other standard classification techniques gave similar results.

Water Vapor Effects

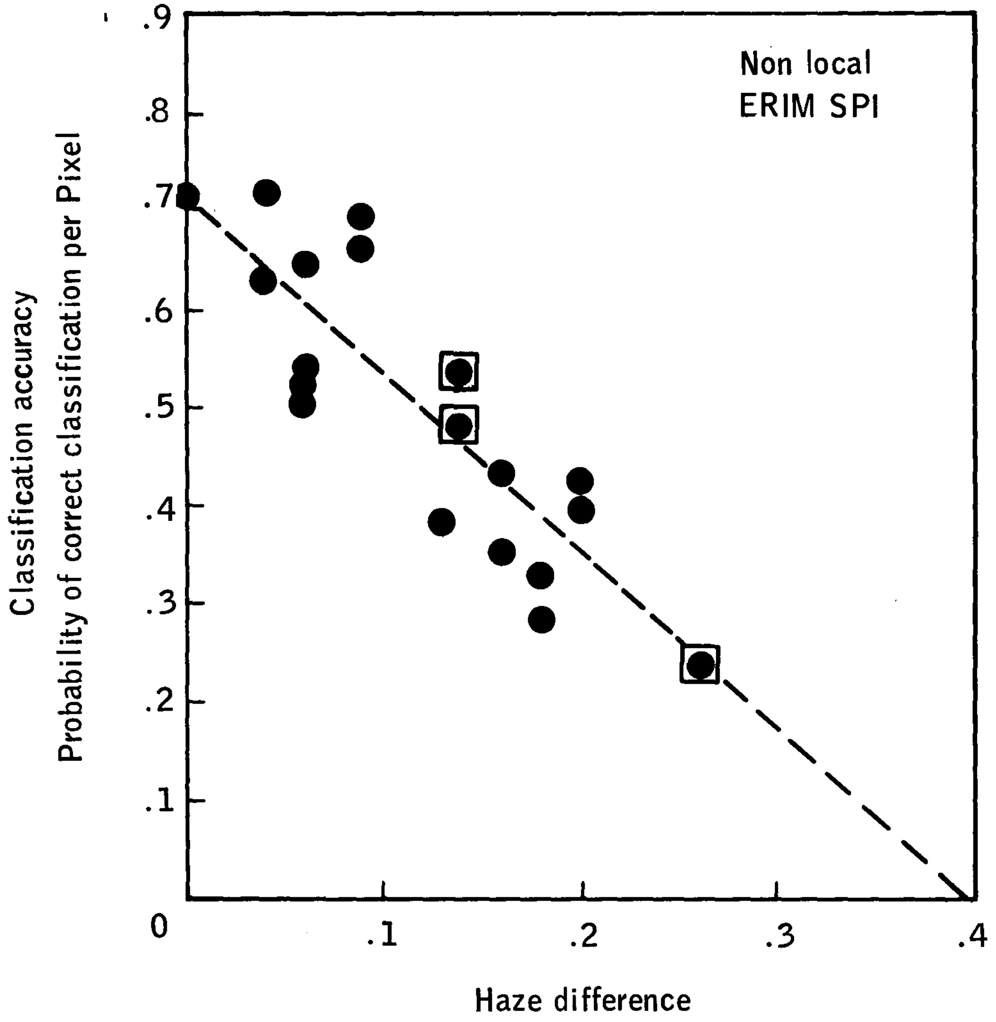
Haze produces absorption and scattering of sunlight which affects all spectral bands. On the other hand, water vapor has absorption bands in the infrared which can affect specific spectral bands. A case in point is Landsat band 7 with a nominal bandwidth from 0.8 to 1.1 microns. Water vapor absorptions occur from 0.81 to 0.84

microns and from 0.88 to 0.98 microns, with the later being the strongest. The average (two-path) transmission of the atmosphere for LANDSAT band 7 as a function of water vapor content is shown in Figure 2 (reference 2). It is seen that humidity variations can have a significant effect on this band. The range of water contents shown in Figure 2 represent the observed range between dry desert air and humid tropical air.

Experimental data showing humidity effects on signature extension are lacking. However, an analytical simulation of the effect was performed, using LANDSAT data for corn and soybeans in Indiana (reference 2). Results are shown in the table below.

Humidity Difference Between Test and Training Fields	Classification Accuracy, Percent	
(cm. pptble. H_20 in optical path)	SOYBEANS	CORN
0.0	98.7	97.6
1.15	91.6	92.3
4.87	46.1	60.4
11.5	8.4	11.4

Humidity differences corresponding to 4-5 cm. of water are often seen across cold fronts.



Effect haze difference between test and training fields on classification accuracy (Illinois, Indiana CITARS data)

FIGURE 2E-1

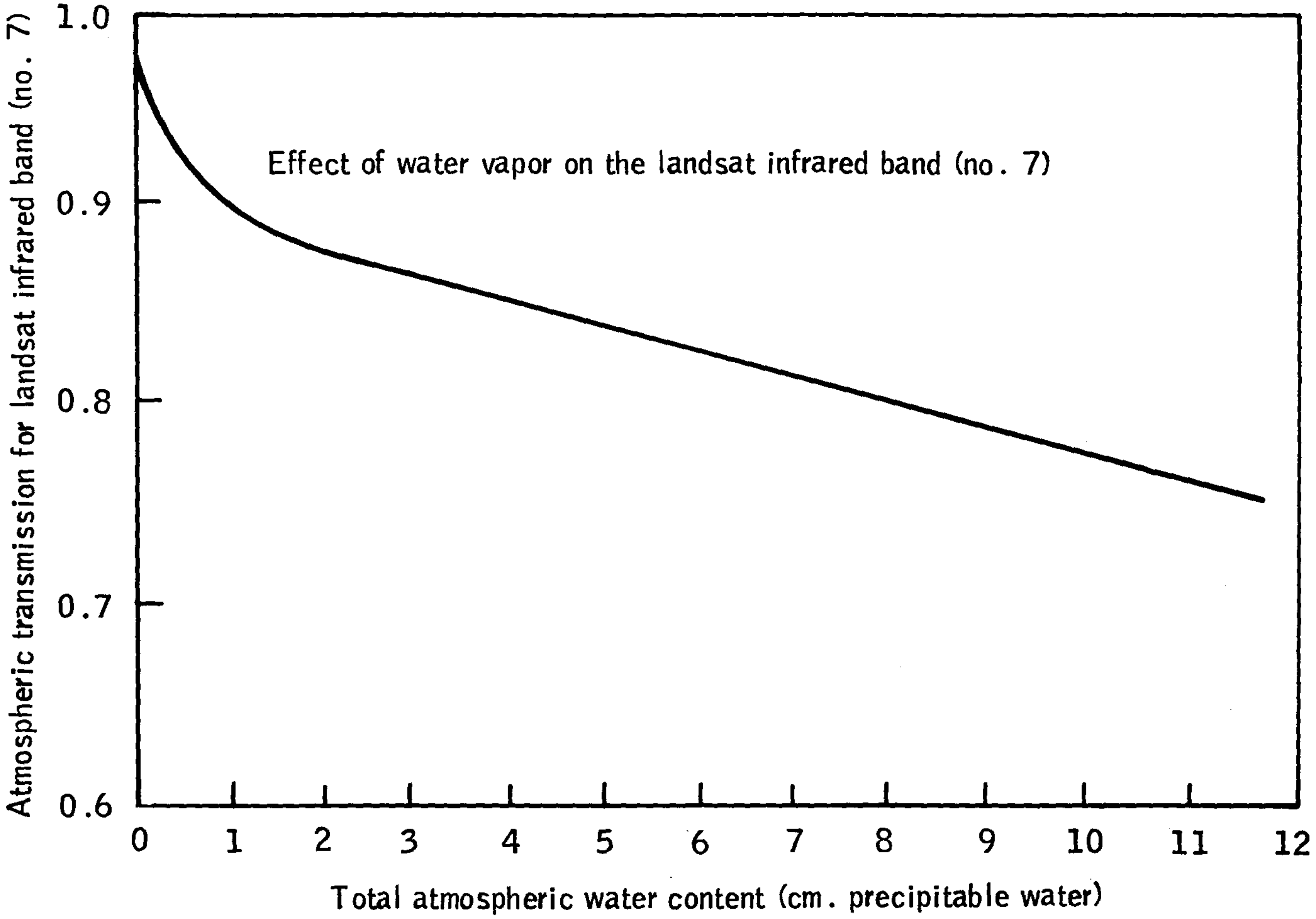

Effect of water vapor on the landsat infrared band (no. 7)
Atmospheric transmission for landsat infrared band (no. 7)
1.0
0.9
0.8
0.7
0.6
0
1
2
3
4
5
6
7
8
9
10
11
12
Total atmospheric water content (cm. precipitable water)

FIGURE 2E-2

Research Requirements

It would be desirable to provide an independent measure of the atmospheric effects. It is recommended that research and development be initiated to define and document methods of estimating haze and water vapor effects for Thematic Mapper users. Suggested approaches are outlined below.

For haze effects, both passive and active measurements are conceivable. Passive methods include the use of contrast reduction factors in cloud shadows, the use of surfaces of known reflectance (water in the infrared, vegetation in the ultraviolet) and possibly also the use of polarization effects. An active method would require the use of a LIDAR to measure the total optical return from the aerosols.

Nearly all vegetated areas contain a pool of water somewhere, and small cumulus clouds are often present. Thus, methods which use the infrared band over water and contrast reduction factors in cloud shadows should be investigated, since no change to the Thematic Mapper would be needed. Haze measurement based on the ultraviolet reflectance of vegetation would require addition of a spectral band centered near 0.4 microns to the Thematic Mapper. This method relies on the fact that the ultraviolet reflectance of vegetation is low (~2%), and potentially could provide optical depths with an uncertainty of ± 0.1 units. (J. F. Potter, unpublished data 1975). Only a coarse spatial resolution would be needed for this band.

LIDAR techniques are not developed for satellite operation. Polarization effects are poorly understood.

For water vapor effects, the best strategy varies with band location. In the reflective region, the spectral band position and width can be changed. The reflective band affected most by water vapor is the band centered near 0.9 microns. The EOS PDG recommended a band 0.8-1.1 microns, while the JSC/ERIM study recommended 0.8-0.95 microns.

It would be desirable to move the long-wavelength cut-off of this band to about 0.90 microns to avoid the strong water band entirely.

Water vapor also affects the 10.4-12.5 micron thermal infrared band. Narrowing the band width to remove the effect is unacceptable, due to the loss of signal strength. An alternate procedure would be to include one or more additional thermal infrared bands in spectral regions adjacent to the 10.4-12.5 micron band. The differences of signal among these bands could be used to establish a water vapor correction for the 10.4-12.5 micron band. The spatial resolution of the added bands could be coarse relative to the 10.4-12.5 micron band, due to the fact that water vapor effects change slowly with distance.

Cautionary Comment on Signature Extension

There are two aspects to signature extension; environmental effects, such as the haze and water vapor effects discussed above, and surface effects, such as changes in soil color or crop development stage. The haze and water vapor effects are only part of the signature extension problem, and corrections for them provide only a partial solution.

ATMOSPHERIC NOISE EFFECTS

Small-scale variations of haze and humidity produce radiance variations across a scene. These variations introduce a form of noise into multispectral scanner image data.

Surface reflectivity differences which are less than the atmospheric noise cannot be discriminated in the image data. This noise can lead to a lowered classification accuracy, even when the mean atmospheric effect is unchanged between test and training fields.

It also leads to a practical lower limit for the noise-equivalent reflectance difference NE$\Delta\rho$ of a multispectral scanner, since there is no reason to make NE$\Delta\rho$ better (less) than the atmospheric noise in the scene.

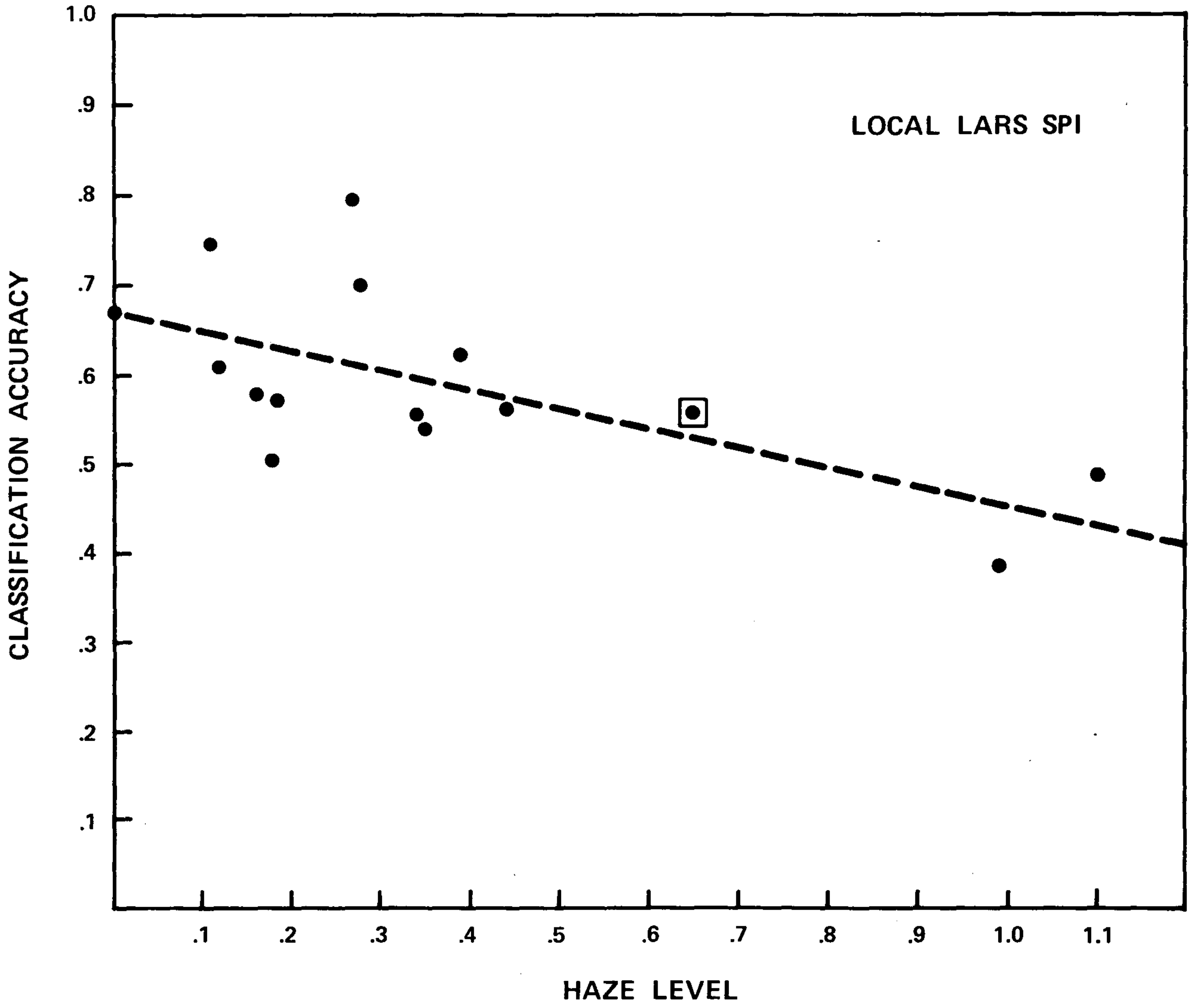
There are few data concerning the magnitude of atmospheric noise and its effect on classification accuracy.

Duggin (ref. 3) has obtained data concerning atmospheric noise in the Landsat spectral bands. He measured the temporal variation of solar irradiance in the four Landsat spectral bands over periods up to an hour. Assuming temporal variations are equivalent to spatial variations, his results give a measure of the atmosphere noise. The coefficient of variation of irradiance ranged from a minimum value of 1.39% to a maximum of 9.77%. The average values ranged from 3.62% (Landsat band 4) to 7.31% (Landsat band 8). The inherent noise equivalent reflectance of a scanner should not be better (less) than the atmospheric noise equivalent reflectance.

For example, for a scene reflectance of 20%, a 3.62% coefficient of variance for irradiation produces an apparent scene reflectance variance of (0.2)(3.62)% or 0.72%. There would be no point in using a scanner with a better NE$\Delta\rho$ than 0.72% over this scene. Further data on the spatial distribution and amplitude of atmospheric noise is needed.

No definitive data on the effect of atmospheric noise on classification accuracy exists. However, data from the CITARS experiment are indicative of the effect. These data are shown in Fig. 3, where classification accuracy, expressed as probability of correct classification per pixel, is plotted against haze optical depth. There is a trend to lower classification accuracies at larger haze optical depths. It is reasonable to expect the atmospheric noise to increase at larger optical depths and to ascribe the decrease of classification accuracy to an increase in atmospheric noise.

Figure 2E-3


LOCAL LARS SPI
CLASSIFICATION ACCURACY
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
HAZE LEVEL

References

1. J.F. Potter, Lockheed Electronics Co., Houston, TX, "Atmospheric Effects in CITARS Data" (unpublished, 1975).

2. D.E. Pitts, W.E. McAllum, A.E. Dillinger, "Effect of Atmospheric Water Vapor on Automatic Classification of ERTS Data, Ninth Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan, 1974.

3. M.J. Duggin, "On the Natural Limitations of Target Differentiation by Means of Spectral Discrimination Techniques" Ninth Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan, 1974.

2E(b). EFFECTS OF CANTING THE MSS SCANNER

The MSS scanner could be canted about 11.8° to obtain a 20% overlap with the Thematic Mapper image, and still obtain coverage for the Thematic Mapper pass on the following day. Geometric distortions produced by this angle change can be adequately compensated by ground data processing. However all existing ground data processing systems would require modification. Atmospheric effects produced by canting are small, but should be evaluated quantitatively.

Appendix G

Subgroup 3 Report

S. VIGLIONE	(LEADER)
F. THOMSON	(CONSOLIDATION PANEL)
D. EBERT	
R. HOFFER	
V. NORWOOD	
W. WIGTON	
C. CHEESMAN	

1

THEMATIC MAPPER RECOMMENDATIONS (Panel 3)
RATIONALE FOR PARAMETER SPECIFICATIONS

Panel 3 chose to define the parameter requirements on the basis of major applications missions. The rationale used was that the applications missions which determine the Thematic Mapper (TM) requirements should be demonstrably economically beneficial, technologically feasible, and have user acceptance and need. The panel identified several such applications missions by reviewing the results of recent cost-benefit studies for economic justification, by considering LANDSAT and other R&D results along with possible TM performance for technological feasibility, and by noting that user acceptance of these missions were either in existance or could be expected to emerge by the 1980 time frame.

Mission Objectives

Several missions, capable of providing meaningful benefits, were reviewed and led to the following objectives.

1. Inventory of World Wide Crop Production

Crop Type:	field grains, soybeans, cotton, corn, rice
Product:	acreage estimation

The crop types selected are those most important in world food production, those which we felt can be identified using satellite MSS data. This latter constraint suggesting combining wheat, oat, barley, etc., into a field grains category.

In reviewing both local and foreign farming practices it was determined that a significant portion of the crop production came from plots in the 10-20 acre size. Ability to accurately estimate acreages of fields in this size range is a secondary objective.

The prediction of crop yield from the spectral reflectance information is felt to be a research question at this time, requiring further analyses and experimental investigations, particularly in the utilization of ancillary (non-TM) and temporal information in developing yield prediction models.

An important part of yield prediction is the detection and severity estimations of crop stress. We felt that a reasonable satellite problem would be the identification of large area extent stress caused by climate conditions, insect infestation and/or induced by man-made practices.

Summary of Objectives - World Wide Crop Production Inventory

Crop Type: field grains, soybeans, cotton, corn, rice

Product: acreage estimation

Secondary Product: localization and mapping of large area crop stress

Considerations: minimum field size 10-20 acres consistent with local and foreign practices

Further Experiments Then Required:

1. Determine ability to separate similar crops (e.g., wheat, oats, barley) and to recognize other important crops (e.g., potatoes).
2. Develop means for using temporal information classifications for increased crop acreage accuracy and for obtaining yield prediction estimates.
3. Develop signature extension techniques to enable routine classification over large areas to aid in world wide inventory.
4. Apply the results of research in 1, 2 and 3 above to refine specific spectral band and spatial resolution requirements for further thematic mapper development.

2. Inventory of Rangeland

The specific mission objective is the estimation of the acreage available, and in use, for animal feed and forage, and the determination of the rangeland productivity. The acreage in use as rangeland is frequently impacted by changes in land use; urban areas are enlarged, agricultural practices are modified and timber stands are harvested and others reforested, etc. Change detection of rangeland acreage becomes an important consideration, but requirements for closely spaced (in time) data sets are significantly less stringent than in the crop identification and crop stress problem.

Summary of Objectives: rangeland inventory

Products: acreage estimation

a) updated acreage estimates using change detection

biomass versus time

Further Experimentation Required:

1. Determine ability to classify biomass into productivity classes (number of animals/acre/unit time) based upon spectral and spatial information available.
2. Determination of required ancillary information (i.e., climate conditions) required to develop biomass predictive models for management of rangelands and rangeland leases.

3. Inventory of Forest Resources

Classification of major tree type and estimates of acreage available is the primary objective. There is limited experimental evidence addressing the ability to specifically define forest classes (e.g., hardwood versus softwood) using satellite MSS data. Timber stand yields are a desirable product but subject to gross errors when estimated from remote sensing imagery available from current satellite instruments. Timber stress was felt to be an important concern, however, the size of stress areas, particularly with insect infestation, may be initially so small that their detection is impractical from satellites.

Summary of Objectives: inventory of forest reserves

Type: Conifers, deciduous, mixed classification

Product: Acreage estimates, stand density

Further Experimentation Required:

1. Develop techniques to determine yield (i.e., board feed/acre) from acreage and stand density estimates.
2. Determine applicability of spectral and spatial information to detection of timber stress (insect infestations). Will likely require the use of temporal information, necessitating development of analytic techniques capable of handling temporal spectral signature information.

4. Inventory of Watershed/Water Resources for Water Management

Water management was considered primarily as knowledge and control of inland lakes, dams, and other large holding and distribution areas. With a satellite instrument, determination of areal extent of snow and water bodies is a viable objective. Classification of vegetation in watershed regions is suggested as a potential means of inferring soil and soil drainage characteristics.

Summary of Objectives: watershed/water management

Type: snow, water classification

Product:
1. Estimates of areal extent of snow and water in watershed regions.
2. Coarse classification of vegetation and vegetation coverage of watershed regions.

Further Experimentation Required:

1. Development of a model predicting, or determining, water content of the snow cover from the spectral information.
2. Integration of vegetation cover information with existing watershed streamflow models.

5. Land-Use Classification

Land-use classification maps have been developed from LANDSAT imagery and proven to be noteworthy in both their utility and the level of interest they generate. With the thematic mapper it is felt that significant improvement can be made in the map products. By controlling geometric accuracy these maps can be periodically updated to provide tools for efficient land development and management.

Summary of Objectives: land-use classification

Objectives:
1. Land-use classification to level 1 (USGS).
2. Land-use classification to portions of level 2 and 3, particularly in vegetation.

Product:
1. Land-use map
2. Map modifications periodically

Further Experimentation Required:

1. Determine level of subclassification of land-use feasible from spectral and spatial information available.

Having reviewed this objective, the panel determined that the ability to categorize major types of food crops, in appropriate field sizes on a regular and timely basis, with consideration of yield per acre and detection of crop stress, should be the motivating factors for determining the thematic mapper parameters. However, judicious review of the other mission objectives would temper the parameter selection process. The following sections present the recommendations and justification as available.

Synopsis of Panel 3 Recommendations

Spectral Bands

Band	Wavelength (10% limits in μm)	Notes
1	0.45 - 0.52	weak justification
2	0.52 - 0.58	
3	0.63 - 0.69	
4	0.72 - 0.80	for research purposes
5	0.80 - 0.91	
6	1.55 - 1.75	
7	10.4 - 12.5	

Radiometric Precision

NEΔρ 0.5% total system in all visible NIR bands for range of reflectances associated with vegetation problems

NEΔT 0.5°K total system, including atmospheric attenuation

Dynamic Ranges

Band	ρmin	ρmax	Tmin	Tmax
1	.02	.25		
2	.02	.75		
3	.02	.78		
4	.02	.90		
5	.02	.90		
6	.06	.55		
7			205°K	340°K

Tentative dynamic range — some further study warranted. Suggest piecewise linear gain curve to preserve some detail in high and low reflectance targets (outside range of reflectances associated with vegetation problems).

Spatial Resolution

as good as possible, consistent with NE$\Delta\rho$ (system) of 0.5%, 30-40 μm seems feasible.

Geometric Accuracy

scene to scene 1/3 pixel registration rms error. Registration to map grid needed, but impossible to specify quantitative accuracy at this time.

Miscellaneous Recommendations

7 day, 197 km swath width system (2 satellites) appears feasible and is preferred because of resonance with 7 day bureaucratic rhythm. The use of two satellites rather than one results in smaller geometric errors to correct by the ground system and thus to potentially lower cost.

Nothing magic about 1.4:1 oversampling--more study required to assess effects on geometric correction and classification accuracy.

Rectilinear preferred over conical scan if heavy use is to be made of low cost ground stations, otherwise not important to the user.

Some prime applications for EOS-TM require 24 hour delivery of some data to user.

Distinct preference for ~11 AM time of coverage because of increased utility of thermal band at that time, to higher radiance levels observed, and to reduced shadowing, as opposed to 9:30 AM. Interaction with cloud cover buildup important in selecting exact time.

2

SENSOR PARAMETERS

Discussed in this section are the panel's recommendations for sensor parameters and the justification, where possible, for these recommendations. The section is organized in five sections: spectral band selection, sensitivity dynamic range and signal-to-noise, spatial resolution, geometric accuracy, and image band alignment.

2.1 Spectral Band Selection

The wavelength bands recommended by this panel were defined on the basis of four factors:

1. Mission objectives defined (by our panel) for this scanner system (agricultural, range, forest, water resources, and land use categories).
2. Spectral characteristics of various species and conditions of vegetation, based upon laboratory (DK-2) and field Exotech spectral measurements.
3. Empirical results using MSS data in which the scanner has established wavelength bands which may not coincide with the desired band widths, but the results indicate the relative value of the general spectral region involved. (Largely based on several different sets of analysis results from Purdue and ERIM, with some consideration of results from Skylab, NASA's 24-channel, and LANDSAT-I scanner.
4. Ability to document value of spectral region and specific band.

There appears to be no solid defensible justification for a band in the 2.09-2.35 μm range. It is often indicated as a valuable band in feature selection processors, but is is highly correlated with the 1.55-1.75 μm band data. Comparison classifications do not tend to indicate that one channel or the other will produce significantly higher classification results. Since there is more energy available in the 1.55-1.75 μm band, this would seem to be the more desirable of the two.

Based upon these considerations, we recommend the following wavelength bands:

TABLE 1

Wavelength Band */	Priority	Value or Purpose	Comments
0.45 - 0.52 µm	Desirable, but not vital	Land use mapping, soil vegetation differences, deciduous/coniferous differentiation	Believe this band would be useful but probably cannot effectively document impact of this band not being present. (Possible research needed) Would be willing to sacrifice this band in favor of 0.72 - 0.80 µm band if further research doesn't offer conclusive evidence to the contrary, and if 7 bands are not possible.
0.52 - 0.58 µm	Necessary	Green reflectance, which is controlled by pigmentation (type and quantity)	Keep it centered in as narrow a band as possible around peak of green reflectance.
0.63 - 0.69 µm	Absolutely necessary	Chlorophyll absorption band	Keep it centered in as narrow a band as possible, centered around maximum chlorophyll absorption band.
0.72 - 0.80 µm	Highly desirable	Vegetation stress detection	Highly desirable for vegetation stress detection, but band should be as narrow as possible, right on the shoulder of the vegetation curve.
0.80 - 0.91 µm or ~0.98 - 1.08 µm	Absolutely necessary	High vegetative reflectance, species identification, water body delineation	Band width not critical, good signal/noise vital, desirable to stay away from water absorption band at 0.925 µm. This band critical for effective species differentiation and identification.

*/ See Table 2 for comments on band width. These recommendations are based on ~10% (rather than ~50%) filter transmission cut-off points.

TABLE 1 (cont.)

Wavelength Band */	Priority	Value or Purpose	Comments
0.80 - 0.91 μm or ~0.98 - 1.08 μm (cont.)	Absolutely necessary		~0.98 - 1.08 μm is better from standpoint of vegetative condition and atmosphere attenuation, but ~0.80 - 0.91 μm may be required because of energy and instrumentation difficulties in 0.98 - 1.08 μm band.
1.55 - 1.75 μm	Absolutely necessary	Snow/cloud differentiation, Vegetative moisture condition	Essential for snow/cloud differentiation (the only wavelength band where this can be done reliably on basis of spectral response). Best single channel for discrimination of vegetation, water, and soil features.
10.4 - 12.5 μm	Necessary	Temperature variation and characteristics, Vegetative density, Cover type identification, Vegetative stress conditions	Band width not critical, but stay above O_3 absorption band at 9.6 μm.

---

*/ See Table 2 for comments on band width. These recommendations are based on ~10% (rather than ~50%) filter transmission cut-off points.

TABLE 2

WAVELENGTH BAND WIDTH COMMENTS

Comments about Increasing Band Width on Lower Side	Wavelength Band Recommended */	Comments about Increasing Band Width on Upper Side
Not critical, other than from atmospheric attenuation and path radiance standpoint.	0.45 - 0.52 µm	Undesirable because of overlap (and therefore higher correlation) with 0.52 - 0.58 µm band
Not recommended (too short of green reflectance peak).	0.52 - 0.58 µm	Desirable to keep band as narrow as possible around green peak, but could be broadened in this direction if necessary, up to 0.59 - 0.60 µm.
Undesirable because band must be kept as narrow as possible around chlorophyll absorption band, but if it must be widened, increased width to 0.62 or possibly 0.61 µm wouldn't be disastrous from a vegetative reflectance standpoint.	0.63 - 0.69 µm	Not recommended (sharp increases of vegetation reflectance occur long of 0.69 µm).
Definitely not recommended (because of sharp decrease in reflectance short of 0.72 µm). 0.73 µm or maybe even 0.74 µm would possibly be better than 0.72 µm.	0.72 - 0.80 µm	Undesirable, in order to keep band as narrow as possible around vegetation reflectance shoulder, but could be increased if necessary from instrumentation standpoint.
Not recommended, because of overlap with 0.72 - 0.80 band	0.80 - 0.91 µm or	Not critical other than from standpoint of water absorption band at 0.925 µm.
Not critical, other than from standpoint of absorption band centered at 0.925 µm.	0.98 - 1.08 µm	Not critical

*/ It is recommended that these band width recommendations be evaluated in terms of filter characteristics involved, and the other system parameters, and possible or necessary changes be reviewed in conjunction with a few life scientists who are knowledgeable about vegetative reflectance.

TABLE 2 (cont.)

Comments about Increasing Band Width on Lower Side	Wavelength Band Recommended */	Comments about Increasing Band Width on Upper Side
Avoid water absorption band.	1.55 - 1.75 µm	Avoid water absorption band.
Avoid ozone absorption band.	10.4 - 12.5 µm	Avoid carbon dioxide absorption band.

---

*/ It is recommended that these band width recommendations be evaluated in terms of filter characteristics involved, and the other system parameters, and possible or necessary changes be reviewed in conjunction with a few life scientists who are knowledgeable about vegetative reflectance.

Evidence in support of the position of this panel on this set of wavelength bands is indicated as follows:

Wavelength Band	Reference No. and Page
0.45 - 0.52	Minimal support in #1
0.52 - 0.58	#1, #2(12), #6, #9
0.63 - 0.69	#1, #2(12), #3(865), #6, #9
0.72 - 0.80	(Fig. 1 attached), #6, #9
0.98 - 1.06	(Fig. 1 & 2 attached), #6, #9
1.55 - 1.75	#1, #6, #8, #10
10.4 - 12.5	#1(pp 77-78 attached), #10

2.2 Sensitivity, Dynamic Range, and Signal To Noise

The panel discussed sensitivity requirements from the point of view of noise equivalent reflectance and focussed on the crop inventory and acreage question because that was considered the prime EOS-TM mission. Also the expertise of panel members was generally concentrated in this area, and we felt that the sensitivity requirements for other high priority EOS-TM missions would be covered by other panels.

Evidence from the crop mapping study of the ERIM study was presented to support the need for $NE\Delta\rho$ of 0.5% [ref 12]. There was some supporting evidence for an $NE\Delta\rho$ better than the ERTS values of about 1% in the position paper by Erickson [ref 13]. He mentioned that the performance of some boundary pixel estimation techniques (useful in making more accurate acreage estimates) may be limited by signal quantization of ERTS. Intuitively, it seems that the system $NE\Delta\rho$ performance should be somewhat better than the reflectance variations we typically see in agricultural crops, but no quantitative evidence for how much better could be given. Although the ERIM study was accepted as credible, there was some feeling that it was not representative of the large area crop survey applications envisioned for EOS-TM. Since at least one aircraft data set (CBWE) exists to permit a more thorough test, such a large scale test is recommened as a research item.

Dynamic range was expressed as maximum and minimum percentage reflectance. Values assumed by ERIM were generally found acceptable, but review was recommended because the EOS-TM mission has apparently been narrowed since the ERIM study was performed. Since the ERIM maximum and minimum reflectances were picked over a broader range of disciplines than is now envisioned for EOS-TM as primary missions, review of maximum and minimum reflectances is suggested. In particular, the maximum reflectance values in 0.52-0.58, 0.63-0.69, and 1.55-1.75 μm bands seem too large.

To help resolve the question of adequate representation of signals in the range of typical vegetation, while preserving some details of signals at the extremes of the dynamic range, the concept of piecewise linear gain curves (different for each channel) was advanced. (See Appendix B for further discussion.) The design of such transfer functions must be done carefully to preserve all the information in the range of signals associated with vegetation classes of interest.

Since the NEΔρ specifications were total system specifications, there should be an apportionment of noise between the sensor and the data digitizer. One approach (Appendix B) would seem to be to make the contributions from the sensor and digitizer equal. A more general allocation rationale has been developed by R. Legault [ref 11]. He suggests assignment of quantizing bin width relative to data signal to noise ratio by consideration of impact on classification accuracy for two materials whose signatures are separated by various distances, and generally arrives at unequal sensor and digitizer noise contributions. The matter of allocation of errors deserves further study.

2.3 Spatial Resolution

The panel concurred with the general philosophy of the ERIM report which argued for a spatial resolution which supported the radiometric and spectral requirements imposed within the constraints of aperture size and available telemetry bandwidth. Some quick calculations by Hughes Aircraft personnel indicate that the desired performance can be obtained at a spatial resolution of about 30m (Figure 5).

While spectral bands and radiometric sensitivity were established prior to IFOV requirements, it must be recognized that IFOV should not be treated lightly in a "whatever results" manner. Crude data [ref 14, volume 5]

Note: 1) Wheat reflectance lower than oats or soybeans in 0.72 - 0.8 μm band
2) Greater contrast between wheat and oats and soybeans in 0.98 - 1.06 rather than 0.8 - 0.91 μm band

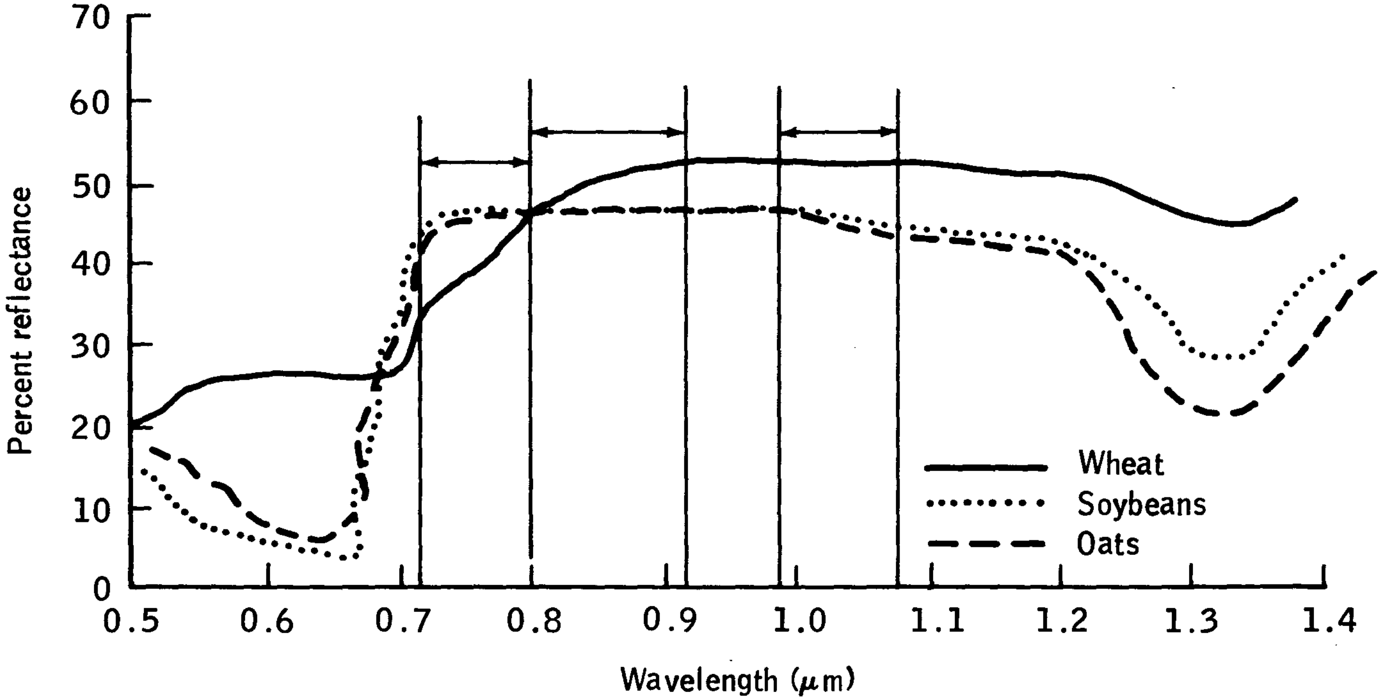


Figure 1. - Reflectance of oats, soybeans and maturing wheat (ref 6).

Note: 1) Good separation of dry soils in 0.72 - 0.8 μm and poor separation in 0.98 - 1.06 μm

2) Good separation of wet soils in 0.98 - 1.06 μm and poor separation in 0.72 - 0.8 μm

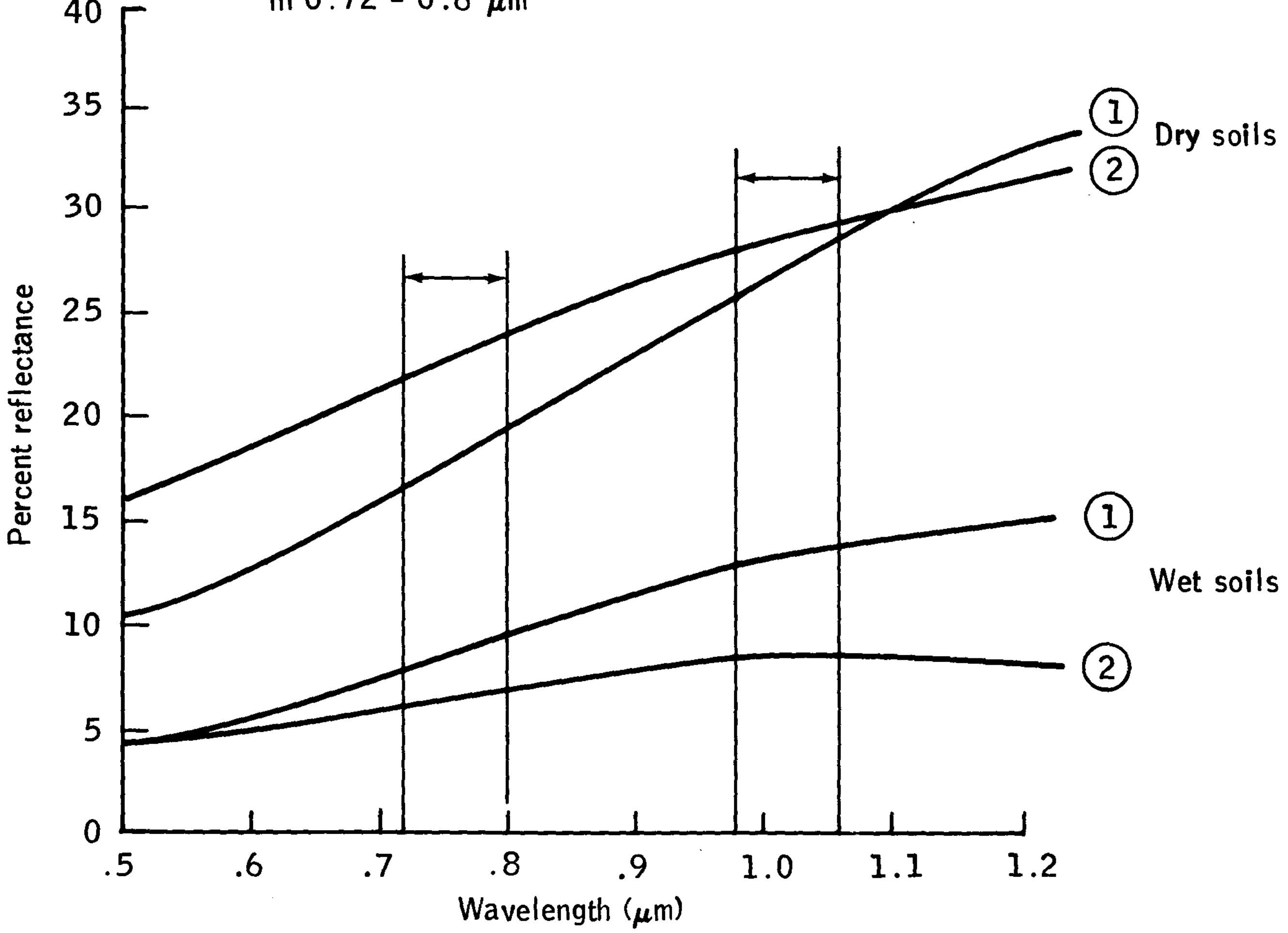


Figure 2. - Reflectance of wet and dry soils.

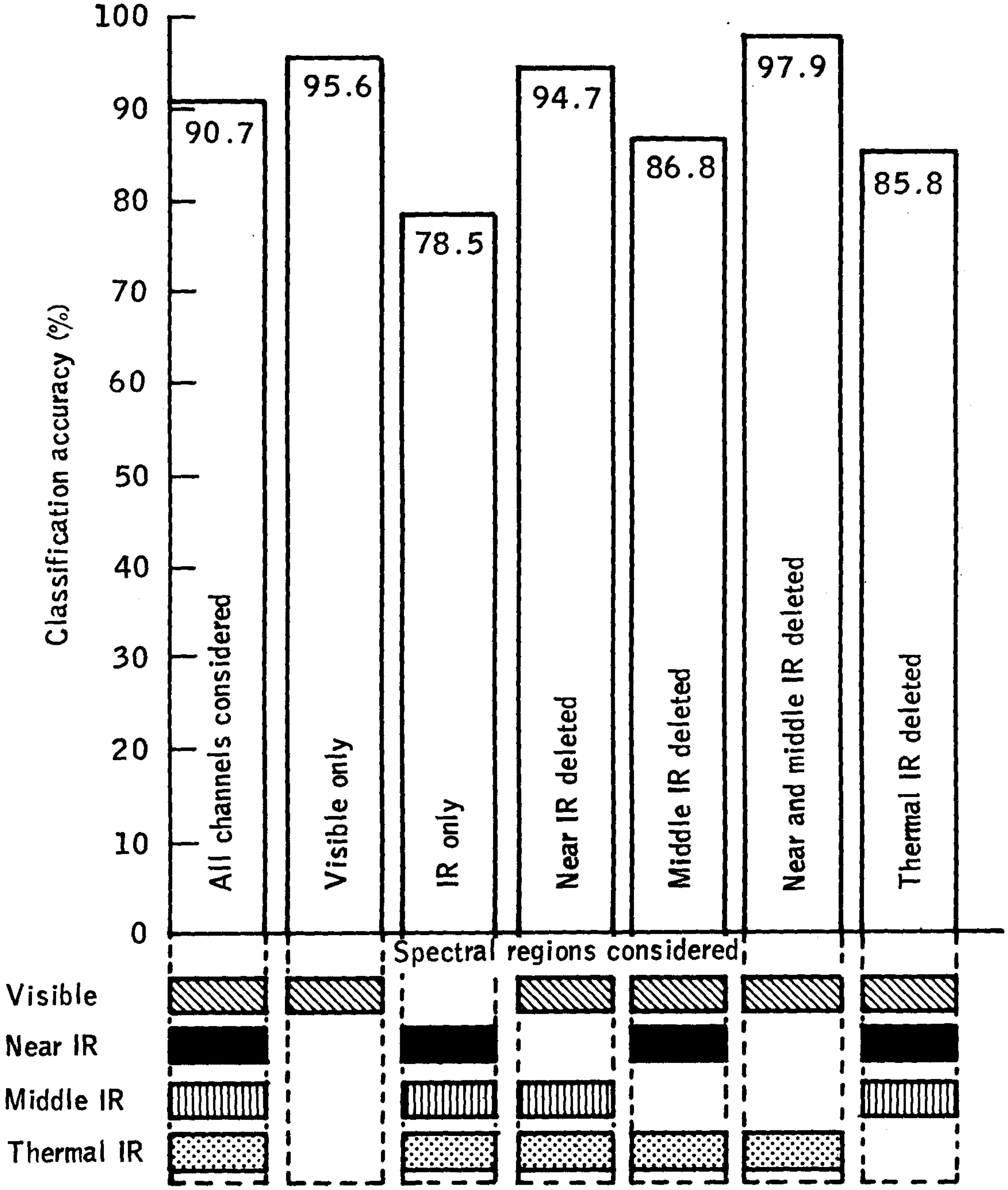


Figure 3A. - Influence of spectral regions on classification accuracy for corn. (ref 1)

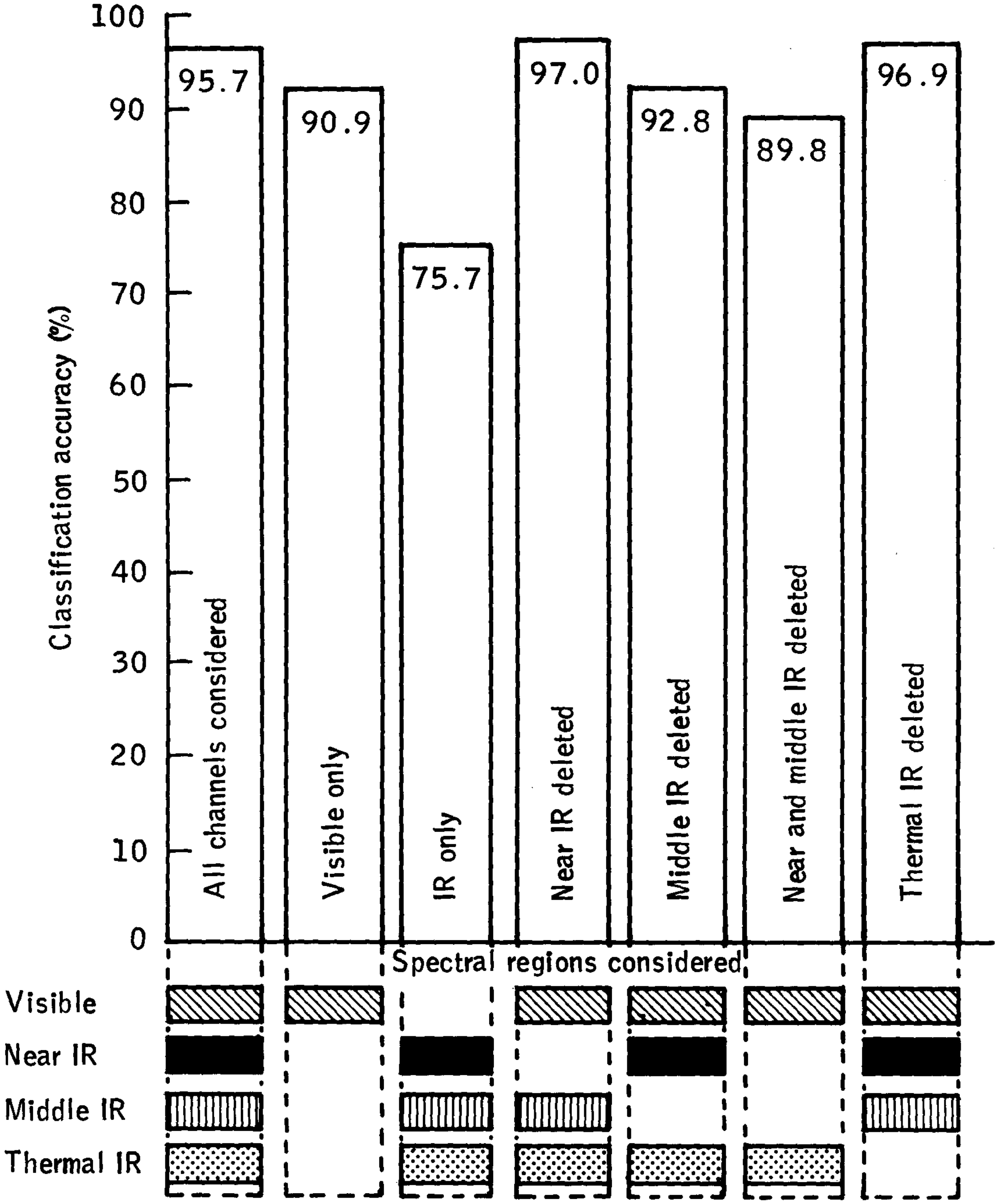


Figure 3B. - Influence of spectral regions on classification accuracy for soybeans.

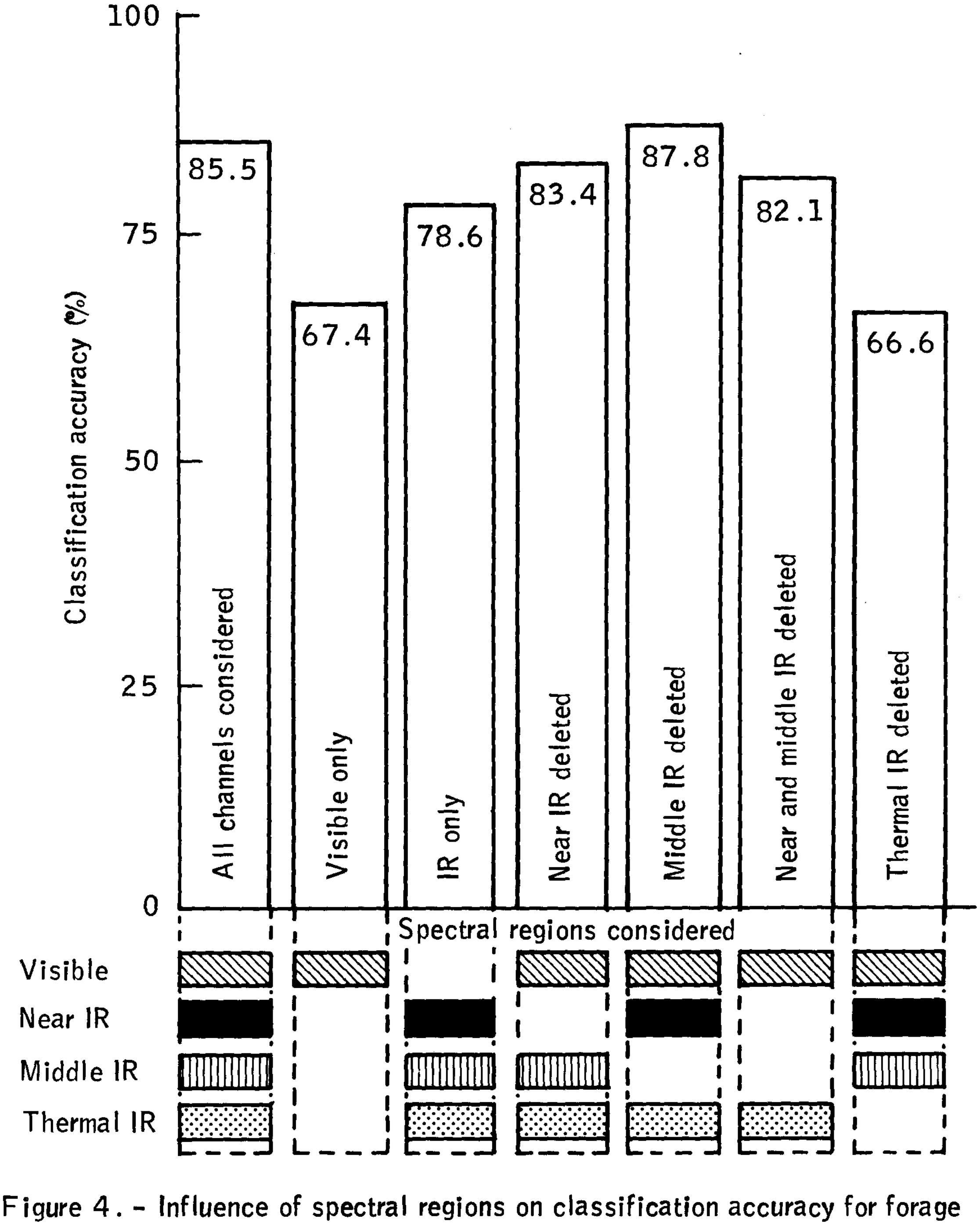


Figure 4. - Influence of spectral regions on classification accuracy for forage (pasture, hay, and stubble). (ref 1)

which exists suggests that some 50% of the world's agricultural acreage is comprised of plots of 20 acres or less and that perhaps 25% of the world's acreage lies in plots of 10 acres or less. The primary mission of crop acreage estimating must consider as a source of sample error the "screening" from the sample of small fields by a course IFOV. If the fields to be served lie in the 10-20 acre range, careful attention to reducing the IFOV as far as possible within the constraints of NE$\Delta\rho$ and bands must be given. The economic benefits due to increased accuracy are still very positive even at IFOV's better than TM. A 30m IFOV should be a design goal.

Generally speaking, to have some hope of correctly estimating acreage for fields (even with regression or boundary estimation techniques) the panel felt that about half the pixels should be field center pixels. Using ERIM reported data [ref 12] for 10 acre fields and 30m resolution, about half the pixels which contain any of the field are field center pixels (that is, pixels which contain only field).

2.4 Image Geometric Accuracy

If LANDSAT type data is to be used to estimate crops on a world-wide basis, then it will be crucial to get data quickly and be able to locate ground observations quickly within the data to estimate training statistics and test data.

This means ground observations will need to be located so that training data and test data can be found quickly. In a system now being considered by USDA-SRS, ground observations are located on 7 1/2 minute quadrangle maps and longtitude and latitude coordinates will be determined. Positional registration of data to a standard geodetic reference coordinate system will be required to locate ground data in TM data. The accuracy required is as scene to scene registration accuracy.

2.5 Image Band Alignment

Registration of pixels between bands within a scene is required to within .1 of a pixel. This is the present state of the art.

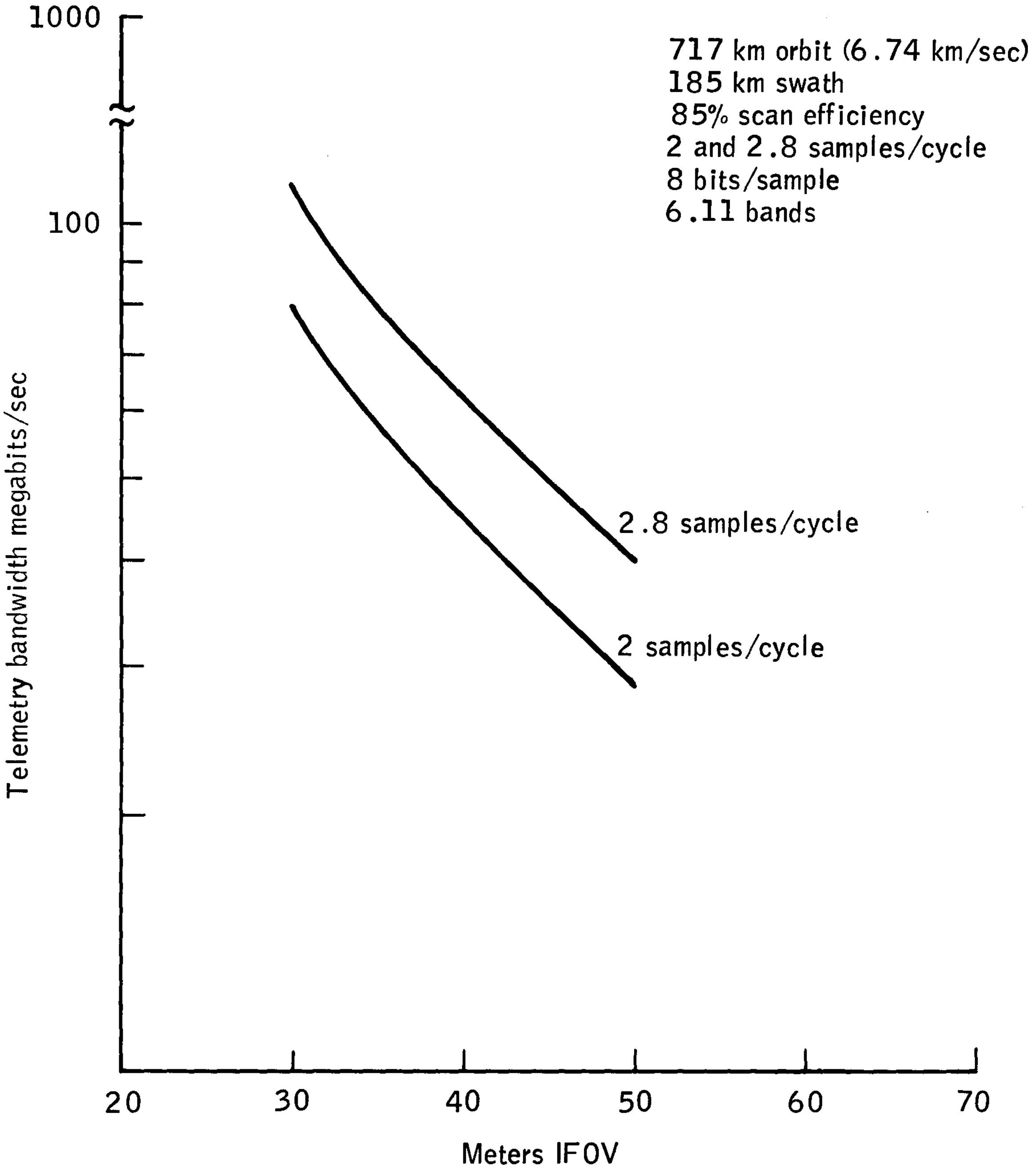


Figure 5. - Telemetry bandwidth vs IFOV.

Registration of pixels between scenes to within .3 of a pixel (rms) is required. This may mean that the data will need to be realigned to some fixed coordinate system.

Temporal information must be easy for the user to obtain. The rationale for such precise scene to scene registration is that if this imagery is to be used for making world-wide crop acreage estimates, then fields as small as 10 acres will be important. In 10 acre fields and with 30m resolution, half of the acres are border acres with mixture problems.

Results of a study of the effect of misregistration of temporal data on classification accuracy are presented in [ref 13]. They support the recommendation for 0.3 rms pixel registration accuracy if multitemporal crop recognition is not to be adversely degraded.

3

ANCILLARY CONCERNS

In this section, several second priority concerns of the panel are expressed. Four aspects are discussed: temporal frequency of observation, image data spatial sampling, conical versus rectilinear scan geometry, and effects of thermal IFOV not equal to visible and NIR IFOV.

3.1 Temporal Frequency of Observation

The repeat cycle and swath width interact. Justification for a given repeat cycle within the range of 7-9 days (2 scanners and/or satellites) must look to user dynamics, phenological dynamics, and orbital mechanics. The first, termed the "bureaucratic rhythm" is the strongest [ref 14]. The repeat cycle of data produced by the satellite, if synchronized with the working week, would lead to unestimated but substantial tangible and intangible benefits. By way of contrast, there appears to be no bureaucratic reason for 8 or 9 days over 7. A small (~10km) increase in swath width, to 195 km, coupled with a 5% equatorial overlap, permits the TM to provide the 7/14 day repeat cycle. Such a cycle is at least as good phenologically (and almost certainly better) and provides the synchronism. It should be noted that if the MSS were to be flown with the TM, the former's swath width would be 10 km less than the latter's and that MSS overlap at the equator would be 1-2%.

With regard to one satellite with 2 TM's versus 2 satellites each with one TM, the concensus was that the bow tie effect for the former would not be negligible (~0.6 pixel overlap at 14° with 20 detectors, 0.36 pixel overlap at 14° with 12 detectors). Since a separate recommendation for system geometric accuracy of 0.3 pixel was made, the choice of number of satellites thus is two.

The principal disadvantage of the offset pointed 2 scanner system is that the terrain effect on geometric error will be increased. In the nadir scan system (single scanner) the terrain error will vary from 0 at the nadir to 15 meters error for a 100 meter terrain elevation at the swath edge. In the offset scan system (two scanners) the terrain error will vary across the swath from 15 meters to 30 meters for a 100 meter terrain elevation. These errors could be corrected only at great expense in data processing either through the use of an exceedingly large number of ground control points or a stored terrain model. Both of these data processing approaches are impractically expensive so that the geometric accuracy specification desired could not be obtained.

A strong opinion by one of the panel members registered was that the dual-scanner system would possess the advantage of simultaneous coverage over a large (195 x 2 = 390 km) swath, thus aiding the training/classification/signature extension problem. The panel suggested that signature extension SRT efforts address this question further.

The time of day, or ascending node time required is determined by cloud buildup, scene radiances versus NE$\Delta\rho$, shadow effects, and thermal channel performance. For the primary mission, crop inventory, shadow effects are minimized by a near-noon orbit, thus minimizing the classification error due to sub-and multi-pixel shadows. Thermal channel effects and scene radiances are also maximized by a near-noon orbit, yielding maximum s/n ratios which also contribute to increased classification accuracy. In addition, the high radiances increase scene contrast and thus apparent spatial resolution (in imagery viewed by eye). With regard to clouds, the panel concluded that although many cloud statistics studies have been conducted, no definitive data existed to choose an optimum node time for worldwide agriculture inventory. Any crop inventory system solution will need to cope with clouds in its design regardless of the time of overflight. If additional study of the problem is possible, it would be helpful in resolving this question. It was noted that two factors argue against a precisely noon orbit--hot spot presence of the anti-solar point and cooler geometry.

The final recommendation is for an orbit node time as near noon as permitted by hot spot and scanner detector cooler geometry (say, 11 AM-11:30 AM) unless additional cloud cover studies demonstrate a strong advantage to world crop survey of an earlier (say, 10:30 AM) orbit.

3.2 Image Data Spatial Sampling

The panel felt that a reexamination of the philosophy of oversampling by a 1.4:1 factor in the scan line direction was in order. This review is predicated by the need to minimize data transmitted to the ground (to conserve telemetry bandwidth) and to avoid unnecessary data processing delays in the ground processor.

While the 1.4:1 oversampling was used in the ERTS system (see Appendix A), sufficient information does not exist for a different choice of sampling rate relative to the IFOV. But because of the obvious data rate and ground station throughput considerations, this issue is worthy of careful study. Results of a Bendix System Division study for GSFC should be reviewed when that study is completed.

3.3 Conical Versus Rectilinear Scan

There is no evidence to indicate that there is significant difference in data quality between conical scan and rectilinear scan data. The panel recommends rectilinear scan, however, for the following reasons:

1. Rectilinear scan data is easier to process on the ground since conical scan data must be converted to rectilinear format for user products. Ground data processing systems will require very substantial additional memory to effect this conversion [ref 15].

2. Although the conical scanner may have a constant path length and therefore a possibly constant atmospheric effect on radiometric accuracy and a constant size IFOV, at satellite altitudes and total scan angle these advantages are negligible [ref 16].

3. The conical scanner views the terrain at varying sun angle and aspect with respect to crop rows and other regular terrain patterns introducing unwanted data variance.

4. Terrain effects on geometric accuracy are less on the average for the rectilinear scanner.

5. Direct readout of scanner data to small local user terminals, if planned, will greatly benefit from and probably require rectilinear scan data to avoid costly development of conical scan data output devices such as displays.

3.4 Thermal IR Band IFOV

The incorporation of the thermal band as an important parameter in a vegetation classification system has been demonstrated in numerous classification studies [ref 12, 17, 18]. The influence on the classification accuracy if the thermal channel IFOV is not the same as the IFOV of the other channels is not known. Since instrument constraints limit the minimum IFOV of the thermal channel it is felt that an IFOV of 3x that of the visible channels should be used. The use of the integer value three provides for convenient registering or centering of the thermal band on the other bands in performing the classification and overlaying the image.

To simplify data processing, registration of the thermal and other bands should be preserved. For a thermal band IFOV of 3x the size of the IFOV's of the other bands, each thermal band IFOV should correspond to a 3x3 group of non-thermal band IFOV's. Both the thermal IFOV and corresponding non-thermal band 3x3 groups should be sampled at the same time. If the non-thermal detector array scans N lines in a single sweep, the thermal detector should be configured such that $\frac{N}{\sqrt{t}}$ = an integer, where t corresponds to the number of non-thermal band IFOV's per thermal band IFOV (t = 3x3 above).

4

PERTINENT SUGGESTIONS AND RECOMMENDATIONS

Several topics were discussed which impact the overall system philosophy particularly as it affects the user and the thematic mapper data utility. It is felt that they deserve mention at this time to assure consideration.

- thematic mapper data should be formatted such that it is readily retrievable in a convenient map coordinate reference system (i.e., latitude-longitude coordinate system)
- data from selected limited regions, defined by this coordinate system, should be accessible on demand
- turn around time should be at least consistent with frequency of observation (i.e., 7 days max). Every effort should be made to enable 2-3 day turn around on selected data segments.

Digital scanner data for selected applications may be required by USDA within 24 hours of the overpass of an area. This may necessitate either improved preprocessing methods or the installation of additional receiving stations and preprocessing facilities. Rationale for this requirement is contained in a paper presented by Mr. Donald H. Von Steen at a recent Digital Image Processing Workshop [ref 19].

APPENDIX A

RATIONALE FOR SAMPLING RATE USED IN MSS

The sampling rate corresponding to 1.4 samples for each IFOV dwell time was selected to produce a system MTF which is essentially the same for the horizontal and vertical direction. This system used an electrical filter with an amplitude of 0.7 at the spatial frequency of $(2\ \mathrm{IFOV})^{-1}$. The sampler was a sample and hold variety which permitted aliasing terms to appear. If a rate of 1 sample per IFOV were used the equivalent MTF at $(2\ \mathrm{IFOV})^{-1}$ would be 0.64 whereas the 1.4 rate used gives 0.81. This advantage combined with the extra safety against aliasing and the availability of data link capability led to the decision to use the more conservative level.

Subsequently it was determined that using an integrate and dump type of sampling offers several advantages. First, the sampler serves as a filter so that the total MTF can be maintained at 0.64 with only 1 sample per dwell time (i.e., the effect of an electrical filter 0.70 times the 1.4 sampling of 0.8 is replaced by a single 1.0 sampling).

Secondly, aliasing is eliminated if the integration for each IFOV is exactly contiguous.

Thirdly, the data rate is reduced according to the curve shown in Figure A-1.

This method of sampling will necessarily be used if CCD detectors become available and would probably be worth incorporating even if conventional detectors are used. The second point of integrating contiguity offers some problem in present day CCD since the collecting areas have inactive strips between.

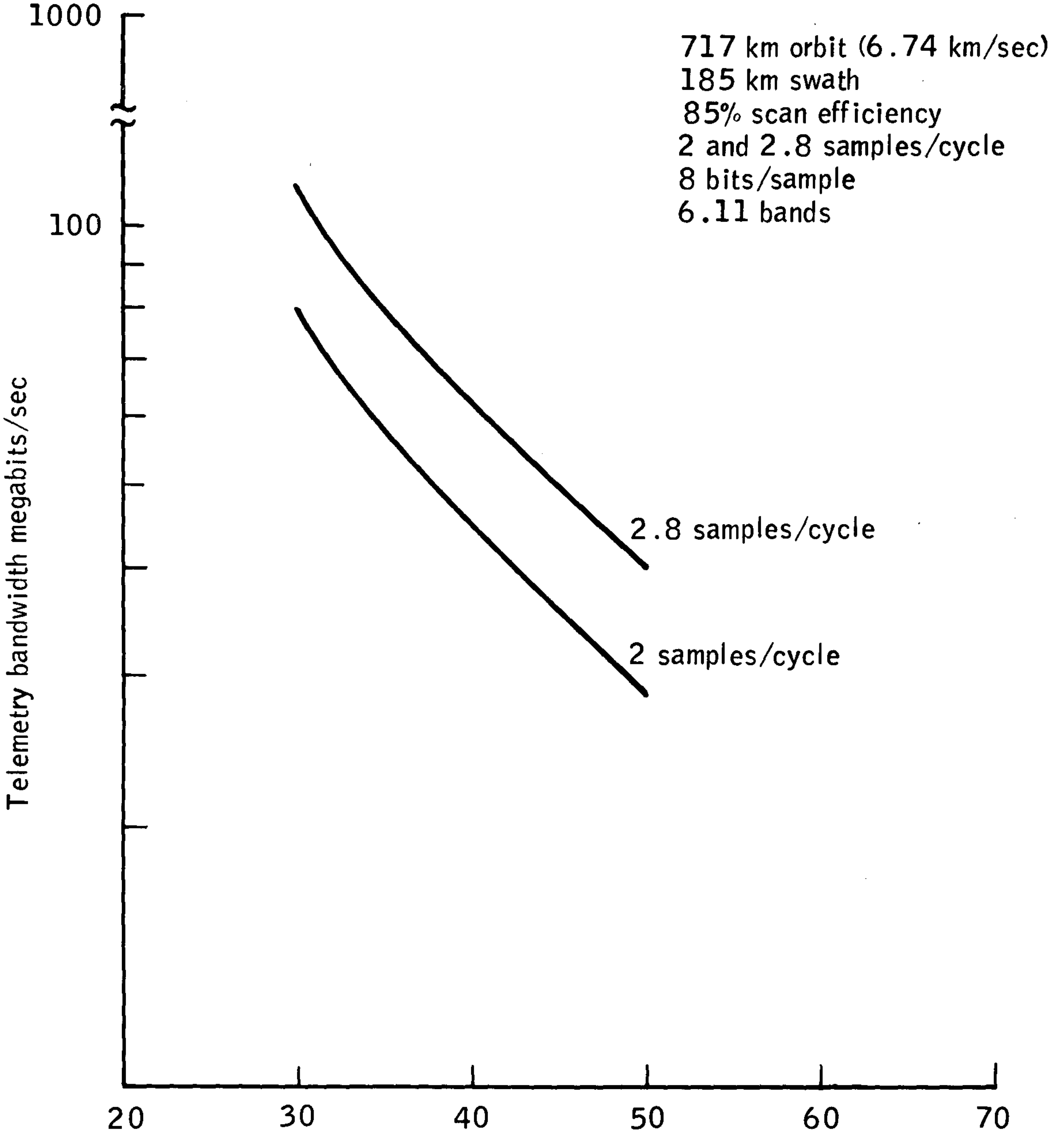


Figure A-1. - Telemetry bandwidth vs IFOV.

APPENDIX B

DYNAMIC RANGE AND AND QUANTIZATION REQUIREMENTS

There seems to be some confusion in relating quantization noise to scanner noise. In order to combine the two types it is necessary to recognize that scanner S/N will be measured in terms of peak to peak signal relative to rms noise. The equivalent statement for quantizing in n-bits is

$$\frac{S}{N}_{QUANT} = 2^n \sqrt{12}$$

Because no encoder is error free it is convenient to reflect the error in n , and arrive at the examples shown in Table B-1.

If we now compare this with the noise values implied in meeting the NE$\Delta\rho$ of .005 we can arrive at the following requirements. (The following suggests a technique and should be refined using a better survey of atmospheric models.)

Consider the ERIM band (.74-.80 μm) because this is most demanding of the encoding levels. At the lowest radiance (.13 mw ster^{-1}cm^{-2} in band) the scanner NE$\Delta\rho$ might be .0035 and the quantization NE$\Delta\rho$ must be the same to preserve the required .005 on an rms basis. When this value is translated to NEΔL using the Rogers and Peacock data (Figure B-1) we have a value of .0041 for each which implies a signal to noise of .13/.0041 or 32. If we now extend this to the maximum stated value of 0.90 (15.08 L times .06 μm) we find a maximum signal to noise of 223.

Examining the table we find that 7 bits would cover the range which can be regarded as the "precision range". It is now possible to devote another bit (8 bits total) to the rest of the range by incorporating different gain levels, as shown in Figure B-2.

TABLE B-1

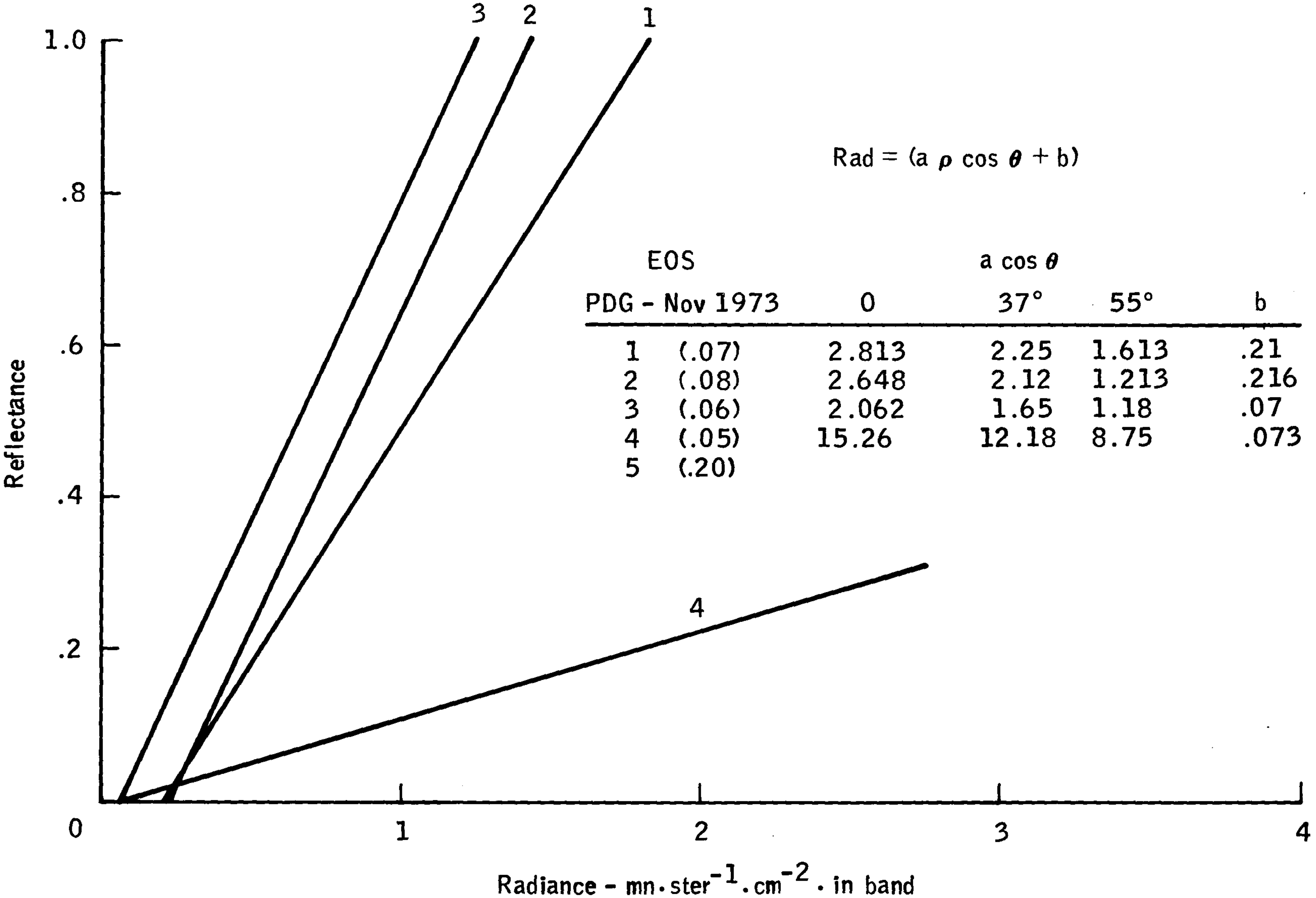
Quantizing Bits Versus Signal-to-Noise

Number of Bits	Equivalent Bits	$\frac{\text{Signal}}{\text{Noise}} = \frac{\text{pk-pk voltage}}{\text{rms voltage}} = 2^n \sqrt{12}$
6	5.6	168
7	6.6	336
8	7.5	627
9	8.5	1254
10	9.5	2508

TABLE B-2

Reflectivities for Bands Below 1 Micrometer

	Precision Range		Complete Range Total
	Min	Max	
Band 1	.02	.25	50
2	.02	.60 (?)	100
3	.02	.78	100
4	.02	.90	100
5			



Rad = $(a\ \rho \cos \theta + b)$

EOS PDG - Nov 1973		a cos θ 0	37°	55°	b
1	(.07)	2.813	2.25	1.613	.21
2	(.08)	2.648	2.12	1.213	.216
3	(.06)	2.062	1.65	1.18	.07
4	(.05)	15.26	12.18	8.75	.073
5	(.20)				

Figure B-1. - Reflectance vs radiance in EOS-PDG bands (Rogers & Peacock) Z = 55°.

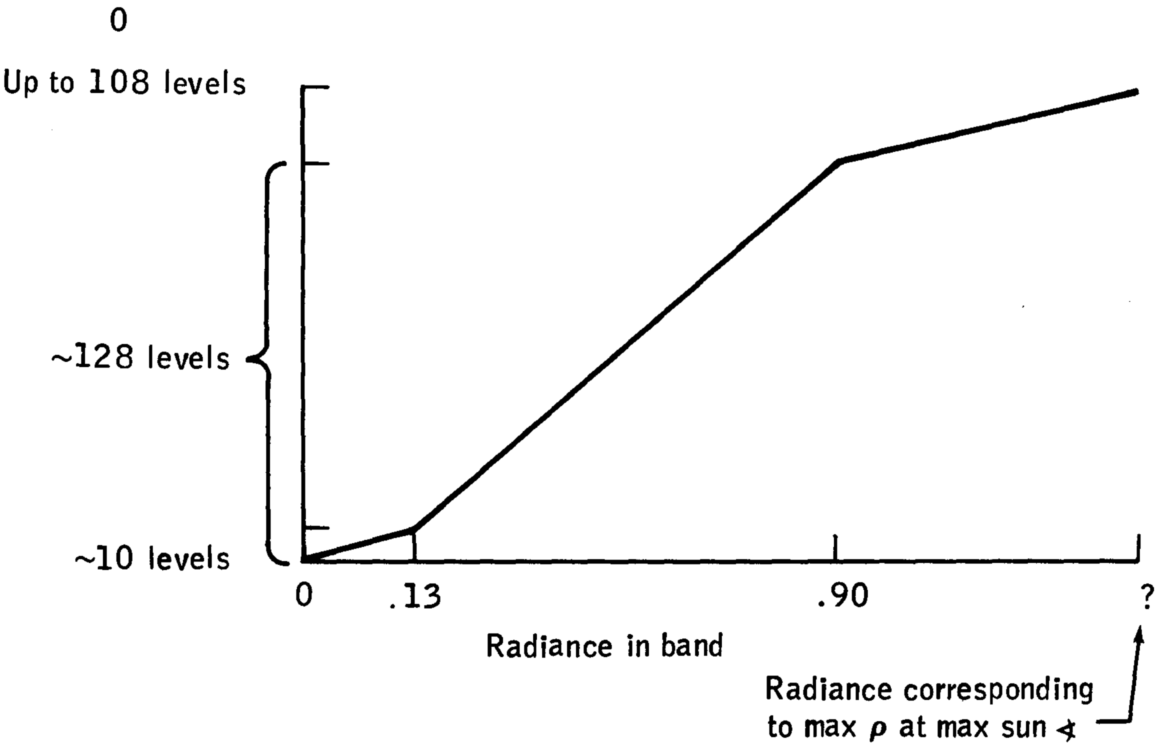


Figure B-2. - Illustration of piecewise linear gain curve.

If the precision range proves not to be any more demanding than in the example shown it is probably desirable to eliminate the lower breakpoint and continue straight to zero, however, consideration could be given to setting the d.c. restore level at a radiance calculated to correspond to the best atmospheric model. The range of reflectivities suggested tentatively for inclusion in the dynamic range or all sun conditions are shown in Table B-2.

RELIEF DISPLACEMENT THEORY

When scanning a scene, the apparent position in the image of objects whose elevation is greater or less than the terrain elevation at nadir will shift relative to their true position on the ground. This shift of position is termed "relief displacement".

Schematically, the effect is shown in Figure 1. An object of height h, at a distance "a" from the nadir, appears in the image at position "a'". The relief displacement is a' - a. Mathematically, this distance is:

$$a' - a = h \tan\theta \qquad (1)$$

where

h = object height in meters
θ = scan angle off nadir
$a' - a$ = relief displacement in meters

The scan angle, in turn is:

$$\theta = \arctan a/H \qquad (2)$$

where

a = object displacement from nadir in km
H = satellite altitude in km

Combining (1) and (2) we get:

$$a' - a = \frac{h}{H}\, a \qquad (3)$$

Equation (3) represents the relief displacement as a function of satellite altitude, terrain altitude (or object height), and distance from the nadir in kilometers. For linear scan systems, relief displacement will occur in varying amounts along the scan line, as "a" varies. Maximum displacement for a given altitude change occurs at the edges of the frame. For a conical scan system, the relief displacement is the same everywhere in the field of view, as a consequence of the constant off-nadir scan angle of the conical scanning system.

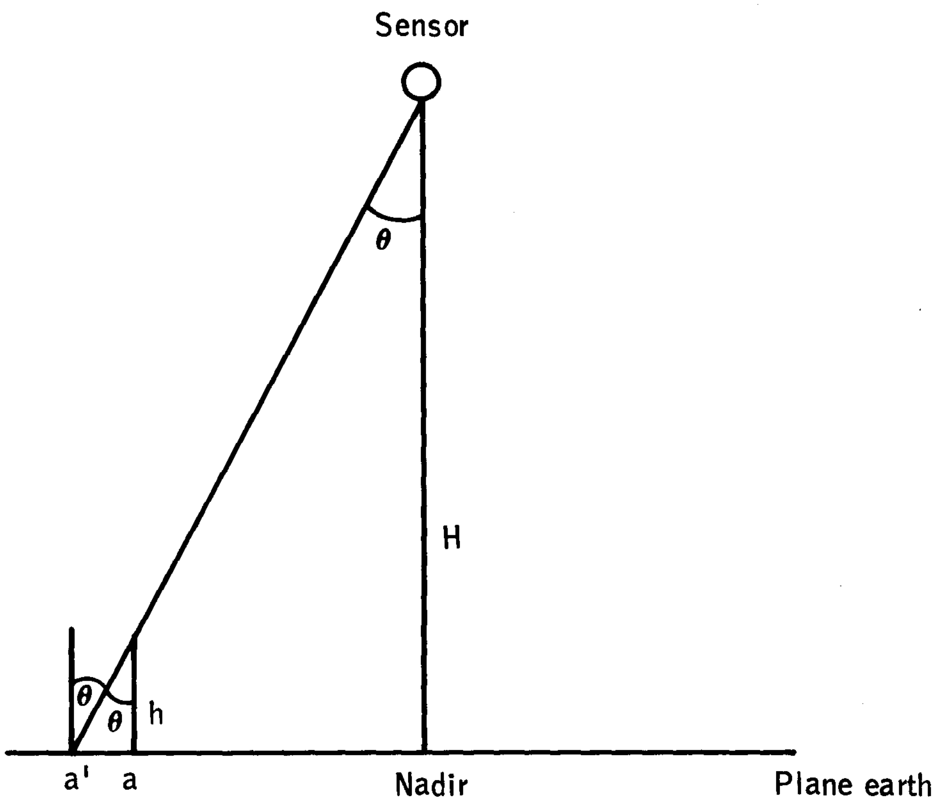


Figure 1. - Illustration of relief displacement.

Plugging in some numbers, we get the following:

H = 704 km

a = 195/2 = 97.5 km (maximum distance from nadir for a 195 km FOV)

h = 100 m

$$a' - a = \frac{100}{704} \times 97.5 = 13.8\text{m}$$

H = 704 km

a = 195 km (maximum distance from nadir for a 390 km FOV)

h = 100 m

$$a' - a = \frac{100}{704} \times 195 = 27.7\text{m}$$

REFERENCES

1. Coggeshall, M. E. and R. M. Hoffer. "Basic Forest Cover Mapping Using Digitized Remote Sensor Data and ADP Techniques." LARS Information Note 030573. Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, Indiana 47906. 131 pp. 1973.

2. Coggeshall, M. E., R. M. Hoffer, and J. S. Berkebile. "A Comparison Between Digitized Color Infrared Photography and Multispectral Scanner Data Using ADP Techniques." Proceedings of the 4th Biennial Workshop on Aerial Color Photography in the Plant Sciences, University of Maine, Orono, Maine. pp. 43-56. July 10-12, 1973. Also LARS Information Note 033174.

3. Sinclair, T. R., R. M. Hoffer, and M. M. Schreiber. "Reflectance and Internal Structure of Leaves from Several Crops During a Growing Season." Agronomy Journal. 63(6): 864-868. LARS Information Note 122571. 1971.

4. Hoffer, R. M. "ADP of Multispectral Scanner Data for Land Use Mapping." Invited paper presented at the 2nd UNESCO/International Geographical Union Symposium on Geographical Information Systems, Ottawa, Canada, August 1-9, 1972. LARS Information Note 080372, 25 pp.

5. Hoffer, R. M. and C. J. Johannsen. "Ecological Potentials in Spectral Signature Analysis." Chapter 1 in: Remote Sensing in Ecology, edited by R. L. Johnson. University of Georgia Press, Athens, Georgia, pp. 1-16. 1969. Also LARS Information Note 011069.

6. Hoffer, R. M. DK-2 Data Set-Selected Spectra. 1975.

7. LARS Staff. "Remote Multispectral Sensing in Agriculture." LARS Annual Report, Vol. 3. Research Bulletin #844, Agr. Exp. Sta. and School of Engineering, Purude University, 176 pp. 1968.

8. Hoffer, R. M. and F. E. Goodrick. Special study on wavelength band selection, carried out at request of NASA Headquarters. 1974.

9. Olson, C. E., Jr. Spectra of Tree Leaves. 1961.

10. LARS Staff. Corn Blight Watch Final Report. 1974.

11. Legault, R. R., letter to A. E. Potter.

12. Thomson, F. J., et al. "Multispectral Scanner Data Applications Evaluation." Volume I User Applications Study, NASA-JSC 09241, ERIM Report 102800-40-F, December 1974.

REFERENCES (cont.)

13. Erickson, J. D. "Position Paper for EOS Parameter Design Review Meeting." ERIM, April 1975.

14. Cheeseman, C. E., et al. "Total Earth Resources System for the Shuttle Era," final reports volumes 1, 2, 3, and 5. General Electric Company, Valley Forge, Pennsylvania, March 1975.

15. Ebert, D. H., et al. "Conical Scan Impact Study, Volume 1 General Central Data Processing Facility," Final Report, Bendix Aerospace Systems Division, NASA Contract No. NAS-5-21903, September 1973.

16. Rogers, R. H. "Investigation of Techniques for Correcting ERTS Data for Solar and Atmospheric Effects," Final Report, Bendix Aerospace Systems Division, NASA Contract No. NAS-5-21863.

17. Viglione, S., E. Nelson, and W. Goldsworthy. "Automatic Crop Classification," McDonnell Douglas Astronautic Company (MDAC), 1972.

18. Nelson, E. and E. Byrne. "Multispectral Imager and Vegetation Classification," MDAC, 1973.

19. VonSteens, D. "A Proposed USDA System to Handle Multispectral ERTS or Similar Digital Data," at Digital Image Processing Workshop, Sioux Falls, South Dakota, November 1974.

Appendix H

Subgroup 4 Report

D. SIMONETT	(LEADER)
J. NICHOLS	(CONSOLIDATION PANEL)
D. LOWE	
P. SWAIN	
S. UNGAR	
W. DRAEGER	
P. CASTRUCCIO	
J. ROUSE	

INTRODUCTION

Prior to discussing specific EOS systems parameters the mission objectives were discussed and narrowed to concentrate on the vegetative resources. First consideration was given to crop identification and crop area estimation. The second consideration was given to non-agricultural vegetation identification and plant stress determination. Inland surface water was considered only if its measurements did not have a significant negative effect on the vegetative analysis.

Recommendations for Spectral Band Locations and Widths.

In this discussion, spectral band recommendations of the JSC/ERIM study, "Multispectral Scanner Data Application Evaluation", are used as a point of departure. The panel accepted the fact that this was justified based on the physical and engineering conditions contained in the report which at least are not contradicted by the empirical evidence presented therein.

(1) 0.45 - 0.52μm — delete

This band has its greatest potential use for hydrological studies. Compared with the other bands, it has limited value for vegetative studies. Also, some of the information contained in this channel can be obtained from other channels which have been retained. The atmospheric effects on this band were also considered when it was deleted.

(2) 0.52 - 0.60μm — retain

Evidence from the aircraft studies supports the utility of this band for agriculture and other vegetation analysis. It straddles the "green hump", making it an important band for the discrimination of green vegetation. It ranked high in its relative ability to aid in the discrimination of forest, pasture, crop, water resources, coastal waters, geology, and urban.

(3) 0.63 - 0.69μm — retain

This is an important band in the chlorophyll absorption region. The 0.69μm limit is critical and should not be allowed to slip higher. The low end may be adjusted as needed to meet other systems requirements. There was some feeling that this band could profitably be split into two bands to capture some information about the shape of the spectral response curve in this chlorophyll absorption region. It was decided, however, that there is insufficient evidence at present to support this separation.

This is the most important single band in the classification of green vegetation with full ground cover. It also ranks very high for water, geology, and urban land use. Studies also rank it high for soil boundary discrimination.

Note: Preliminary Results of GISS Study (S. Ungar).

Investigations with high resolution aircraft spectra indicate that the primary information necessary for making suitable discrimination in a variety of vegetative applications occurs only in the spectral regions corresponding to chlorophyll absorption features. The ERIM band configuration characterizes the chlorophyll absorption region corresponding to MSS-5 by one band (0.63 - 0.69μm). A two-channel characterization of this region, used in conjunction with other channels, would provide some information as to the shape as well as the relative depth of this absorption feature. Rearranging the second (0.52 - 0.60μm) and third (0.63 - 0.69μm) ERIM bands to cover this region as follows: Band 1, 0.60 - 0.645μm and Band 2, 0.645 - 0.69μm. Simulation studies from high resolution aircraft spectra indicate that this band placement enhanced discrimination for rice fields at different stages of maturity, and well as discrimination between fir and pine stands.

The above comments are based on data obtained from aircraft with spectral coverage from 0.4 - 1.05μ and in approximately 600 10 Å-wide channels with an instantaneous field of view of approximately 60 by 60 feet.

(4) 0.74 - 0.80μm — added

This band is useful for sensitive vegetation studies including biomass estimation and determination of plant stress. This band, although highly correlated with the 0.80 - 0.91 band also recommended, does not adequately replace it in all situations of vegetation analysis.

Position Statement by John Rouse.

Point of Issue.

The ERIM EOS TM recommendations specifically omit the entire 0.70 - 0.80μm band. The apparent rationale for this decision is based on data that indicates that the LANDSAT channel 6 (0.70 - 0.80μm) band and band 7 (0.8 - 1.1μm) have been found to be highly correlated in many data analysis studies. Therefore, it seems unnecessary and redundant information to have both channels on the thematic mapper.

Although it is probable that LANDSAT band 6 and band 7 will be highly correlated for reflectance measurements in healthy vegetation, the two bands are essential for reflective measurements involving the investigation of scenes composed of both dry and green vegetation; i.e., scenes characterized by vegetation under stress, spring green-up, or brown-out, or drought caused by frost.

Reflective Characteristics.

The reflection spectrum of the green vegetation is characterized by observations in the 0.6 - 0.7μm region and high reflectance in the 0.7 - 1.0 region. There is a sharp transition region in the 0.68 - 0.72μm range. The slope of this transition is characterized (in natural scenes) by the relative strengths of the various components comprising the total scene, e.g., vegetation and soils or green and dry vegetation. Soils have a relatively uniform reflectance spectrum in the 0.6 - 1.1μm region, dry biomass may be high reflective in the 0.8 - 1.0μm range; however, the absorption in the 0.6 - 0.7μm range is not predictable from this information. The maximum differences between green and dry biomass occur in the 0.7 - 0.8μm range (positive differences) and 0.6 - 0.7μm range (negative differences).

Rationale for the Channel.

Applications requiring the monitoring of the change in vegetative condition require the monitoring of the difference between green and dry biomass. These studies include monitoring of stress condition caused by disease or moisture deficiency, monitoring of the spring green-up for phenological studies, or the estimation of brown-out to determine the length of growing seasons. These phenomena may be better addressed with data in the 0.74 - 0.8μm channel than with data in the 0.8 - 0.95μm band. This also assumes a 0.6 - 0.7μm channel available in the system. Evidence of this effect was found in a rangeland assessment study using LANDSAT I data by Texas A&M University. The correlation with green biomass of (band 5 minus band 6)/(band 5 plus band 6) data was significantly better than with (band 5 minus band 7)/(band 5 plus band 7) data. This study included rangeland sites located throughout the Great Plains (Texas - North Dakota). Available ground based spectral data of green and dry biomass support this rationale. However, the data analysis is limited. Although present indications support this channel for selection, especially as a trade-off with the 0.45 - 0.52 channel, the rationale for selection needs further investigation due to the fact that the LANDSAT I data analysis cited here used the 0.7 - 0.8μm data which is influenced by the dynamic transition region between LANDSAT band 5 and band 6. In addition, there exists inadequate ground base and airborne data to support the channel selection at this time.

Recommendations.

The 0.74 - 0.8μm channel should be added to the thematic mapper in place of the 0.45 - 0.52μm channel as a preliminary design specification. A separate study to determine the cost effectiveness of the selection of this channel, based on ground spectra and airborne spectra measuring green, dry, and green-dry vegetation should be conducted. This could be one of the initial efforts in the proposed rangeland ASVT.

(5) 0.80 - 0.95μm modified to 0.80 - 0.91μm

The upper limit of this band was reduced to 0.91 to eliminate the effects caused by the water absorption band in the 0.92 region. Empirical studies have indicated that this band is well suited and important for vegetative studies and water resources related studies. It is the flat area of high plant infrared reflectance. It is an important band for crop identification by contributing strongly to classification accuracy for growing crops, soil-crop contrast and water/land boundary delineation. This band ranks second after the 0.63 - 0.69 band for green vegetation analysis. This band is not as critical for within class discrimination such as the within water discrimination and within soil discrimination.

(6) 1.55 - 1.75μm — retain unchanged

Despite possible signal-to-noise problems with this band, its utility for vegetation classification and discrimination of clouds from snow is well documented. This band is also important for the estimation of moisture in vegetation. It has been demonstrated that this band is highly sensitive to moisture content of dry vegetation which is extremely important to wild land fire control agencies. The band is also important for determining moisture in live vegetation. Because of the extremely low reflectance from water, even turbid water, this band is ideal for surface water mapping. Surface soil moisture is also readily obtained shortly after rainfall in this band, or when surface water is present from irrigation. Because of the low signal available in this area, the resolution should be degraded optically rather than the band broadened to improve the signal-to-noise ratio. The filter function used should eliminate as much as possible the interference caused by the water absorption bands on either side of this band.

(7) 10.4 - 12.5μm — retained unchanged

The importance of the thermal channel for vegetation classification is well demonstrated based on studies done with aircraft multispectral scanner data and Skylab S192 data. Although studies have not been specifically conducted to determine the utility of the band, it is probable that this band will provide significant information for determination of plant stress because of the low thermal inertia of vegetation, in particular, vegetation with low water content. The above discussions were based on bands defined at the 50 percent point with the filter rolloff no less sharp than that of LANDSAT I and LANDSAT II multispectral scanner systems. Where specific limits must be adhered to due to vegetation characteristics or atmospheric characteristics, they have been explained in the text.

References.

1. Coggeshall, M., and R.M. Hoffer, "Basic Forest Cover Mapping Using Digital Remote Sensor Data and ADP Techniques", Information Note 030573, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana 47907; March 1973.
2. Coggeshall, M., R. Hoffer, and J. Berkibile, "A Comparison Between Digital Color Infrared Photography and Multispectral Scanner Data Using ADP Techniques", LARS Information Note 033174; March 1974.
3. Corn Blight Watch Experiment Final Report, Vol. 3, NASA Earth Resources Program, Johnson Space Center; May 1974.
4. Biehl, L., and L.F. Silva, "Machine Aided Multispectral Analysis Utilizing Skylab Thermal Data for Land Use Mapping", Proc. Purdue Symposium on Machine Processing of Remotely Sensed Data, Purdue University, West Lafayette, Indiana; June 1975.
5. LARA Annual Report, "Remote Multispectral Sensing in Agriculture", Vol. 4, Research Bulletin 873, December 1970.
6. J.C. Schleter, V.R. Weidner, and J.D. Kerder, "Spectral Properties of Naturally Occurring and Man Made Materials", NBS Rept. 8626, December 1964.
7. NASA, SP335, "Advanced Scanners and Imaging Systems for Earth Observation", p. 429.
8. NASA, SP335, p. 429 and 434.
9. NASA, SP335, p. 434.
10. W. Wolfe, "Handbook of Military Infrared Technology", ONR, 1970, p. 228.
11. W. Rody, C. Olsen, "Estimating Foliar Moisture Content from Infrared Reflectance Data", Third Biannual Workshop for Color Aerial Photography in Plant Sciences, March 1971, ASP.

General Recommendations for Further Studies and Spectral Characteristics.

It is evident that there is a tremendous amount of data on the spectral characteristics of vegetation in both the wild land and agricultural environments. It is just as apparent that there has been no coordinated program to collect, analyze and interpret the spectral data on a multidisciplinary base to obtain the information necessary to optimize channel selection for future satellites. It is therefore recommended that such a coordinated program be undertaken as soon as possible in hopes that the results could have a significant impact on the shuttle era scanner systems and proposed aircraft multispectral scanner systems.

RADIOMETRIC RESOLUTION (SENSITIVITY, DYNAMIC RANGE, and SIGNAL-TO-NOISE RATIO)

The radiometric accuracy required for acceptable classification accuracy is a function of the subject and its background. The ERIM report is the only known source of data on the effects of sensitivity on classification accuracy. Unfortunately time did not permit a careful analysis of this report in preparation for preparing the document. It is the feeling of the people on the panel, however, that a minimum NE$\Delta\rho$ of one percent (see Table) is required in all the reflectance channels. Sensitivity is based on visual observations of the spectral data presented in the report for vegetation and soils phenomena. Although numerous spectral curves were presented very little information was provided on variability of the spectral data within crops and between crops. Because of this lack of information on variability, precise recommendations on NE$\Delta\rho$ cannot be made at this time.

The spectral data also shows that the reflectance of the scene can vary from four percent to forty percent in the 0.52 - 0.60μm region, four to fifty percent in the 0.63 - 0.69μm region, two percent to seventy percent in the region from 0.74 - 1.75μm region. This variation in target reflectance should be observed under the most favorable illumination levels (associated with zero latitude in June) to the least favorable illumination conditions (associated with latitudes of 45 degrees in December).

In the absence of on-board data processing, these variations in signal level require a dynamic range of 280 levels. Because the illumination level varies steadily during an orbit, because of latitude changes, it is recommended that some form of automatic level control be incorporated in the system to keep the dynamic range within a factor of 100. An automatic gain control system is not recommended. A switched fit level setting or a nonlinear gain should be considered. In this way, an 8-bit digitized signal will be sensor-liminted and not digitization or noise limited. Of primary concern is the ability to reproduce radiometrically correct results for ground processing. The NE$\Delta\rho$ of one percent is based on total systems signal-to-noise when the digital tape is produced for applications. It includes sensor signal-to-noise, on-board analog processing noise, quantization noise and transmission noise.

Table of $\rho_{min} - \rho_{max}$ and $\Delta\rho$

Worst Case:
Latitude 45°, Winter Solstice

	Band (μm)	$\rho_{min} - \rho_{max}$	$\Delta\rho$
(1)	0.52 - 0.60	4 - 40%	1%
(2)	0.63 - 0.69	4 - 50%	1%
(3)	0.74 - 0.80	2 - 70%	1%
(4)	0.80 - 0.91	2 - 70%	1%
(5)	1.55 - 1.75	2 - 70%	1%
(6)	10.4 -12.5	270°K - 320°K	0.5°K

The panel supports the notion of a contemporaneous water monitoring system with a two-band, very coarse resolution nadir pointing line trace radiometer scatterometer. This system will allow better evaluation of water vapor effects and the elimination of these effects from the following bands: 0.52 - 0.60μm, 0.63 - 0.69μm, 1.55 - 1.75μm, and 10.4 - 12.5μm. This procedure will lead to an improved calibration of the system, improved accuracy of crop and vegetation identification and the development of a data base and the required experience to locate and correct for atmospheric effects.

SPATIAL RESOLUTION

It seems to be an accepted fact that there is very little evidence to support any particular spatial resolution between 30 and 60 meters. However, most people agree that finer resolution is better in some intuitive sense.

Some evidence does exist, however, that supports this intuitive feeling. For example, if double sampling schemes are used to obtain acreage estimates acceptable to agricultural users, significant improvements in precision of the estimates will be obtained with the higher resolutions. This double sampling scheme has proven cost effective with LANDSAT data as the first stage and aircraft data as the second stage in the inventory. The increase in precision comes from two sources: first, an increase in accuracy in classification of picture elements within a sampling unit through the reduction in the significance of the field boundary effect; secondly, the improved accuracy of locating the perimeter of the sampling unit with the higher resolution imagery will improve the error in locating the sample unit on higher resolution imagery approximately 45 percent in terms of absolute area. The combined effect of classification accuracy and locational accuracy will reduce the variance of the final estimate significantly. The question of the cost effectiveness of the increased resolution must be thoroughly investigated before the final specifications are determined.

In wild land areas linear features and point features such as roads, streams and pond and water will be more readily observable with 30-meter instantaneous field of view (IFOV) than with larger IFOVs. However, we do not have any quantitative evidence to support this statement.

Also in the wild land environment the discrimination of individual plants will not be possible with 30-meter IFOVs. The 30-meter IFOV will greatly improve the within and between plant community discrimination however.

Specific Recommendations

The panel's position is to maintain spectral bandwidth and signal-to-noise ratios as listed in the table at the cost of increased spatial resolution, if necessary, to achieve the bandwidth and signal-to-noise. The sacrifice in spatial resolution should be done in the following manner. If 30-meter resolution can be obtained in bands (1), (2), (3) and (4), this will be acceptable. We will also accept, if necessary, 60-meter resolution in band (5) (1.55 - 1.75μm) and 90-meter resolution in band (6) (10.4 - 12.5μm). This increase in IFOV in bands (5) and (6) should only be considered if inadequate signal-to-noise and spectral bandwidth is obtained if a 30-meter resolution is retained.

Additional Justification of Higher Spatial Resolution

High spatial resolution will improve recognition of fields and field boundaries of the size commonly found in China, India and some parts of the United States and Europe. The accuracy of acreage measurement improves directly as a function of resolution and will reduce the required sample size in cost of processing by reducing the number of mixed picture elements within a scene. The high spatial resolution is important for users who are primarily concerned with manual photointerpretation. High spatial resolution will be important to the users interested in land use, hydrology, range, forestry, flood plain mapping and drainage density mapping because the type of data for ground conditions they are working with is more point and linear in nature where there are very few situations where large areas such as agricultural fields exist.

An Alternate Approach to Achieving Area Estimates at High Spatial Resolution

Double sampling schemes utilizing low resolution multispectral scanner data and high resolution photographic data have proven cost effective for precise acreage estimation and crop identification. Studies also indicate that a mixed resolution system with a very high resolution imaging system to determine boundaries and specify subpixel processing could probably be cost effectively implemented. Based on this it is recommended that a high resolution system be flown in conjunction with the thematic mapper to provide the spatial resolution necessary to achieve area estimates and identification of acceptable accuracy on an international basis where aircraft imagery cannot be obtained. There are several approaches that could be used to implement such a system. First a high-resolution pointable imager with approximately 10-meter ground resolution could provide the high resolution information on a sampling basis, reducing the data load while retaining enough information to accomplish the estimates desired through a sampling scheme driven by the lower resolution multispectral scanner data. A second approach could be a swath system that would allow the acquisition of a substrip of the thematic mapper image on a selectable basis. For example, a quarter swath width could be obtained providing a 25-mile wide strip of high resolution data to use in the double sampling and the subpicture element processing modes. The ultimate, but probably not optimum, system would be a full swath width, 8 - 10 meter resolution system utilizing several sensors at a lower spectral resolution and lower $\Delta\rho$ to provide the high resolution, full 100-nautical mile swath for subpicture element processing and field-by-field or sampling unit-by-sampling unit area estimation. Still another alternative suggested by one panel member would be the switching of spatial resolution between a high-resolution, broadband system and the multispectral system documented here.

GEOMETRIC ACCURACY

It is recommended that the final products of the total system be within the following specifications: the band-to-band registration of a single date of imagery be 0.1 picture elements; the location of individual picture elements from a single date be within 0.5 picture elements; the registration of all bands of all dates to be registered to a common map projection (transverse Mercator); the full scene registration to the above projection within 0.5 picture element. It is understood that the scanner on board the spacecraft could not achieve these accuracies and it would be accomplished through the scanner parameters, spacecraft orientation parameters and complex ground processing procedures.

Two issues must be addressed when considering image geometric accuracy after the band-to-band registration of a single date has been accomplished: first, the pass-to-pass registration of the imagery from the same tracks and from adjacent tracks and secondly the registration to a geographic coordinate system. Although these two image-to-image and image-to-ground registration problems are not independent, it is worthwhile to consider them separately at this point.

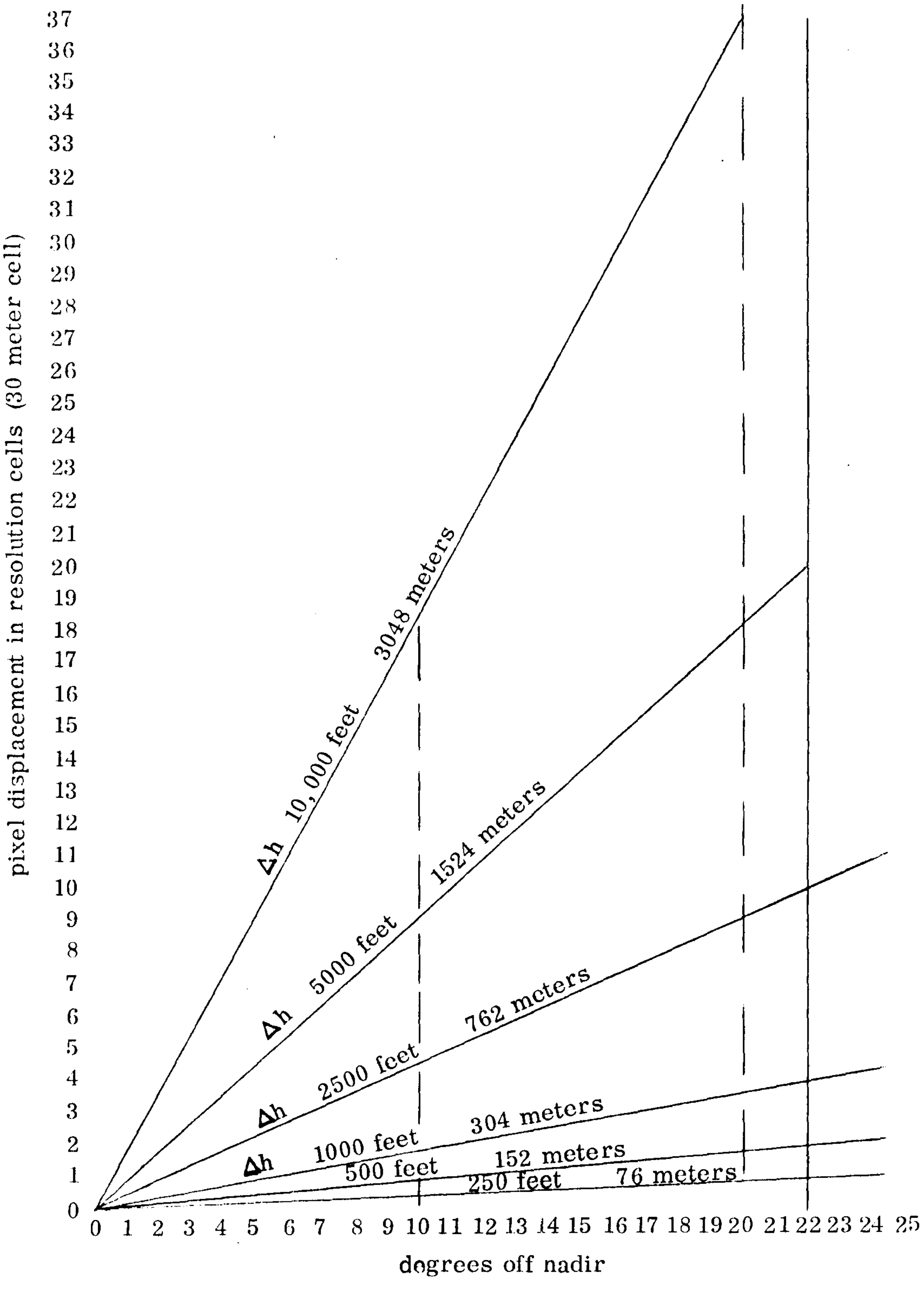
Taking the registration of the image data to a common coordinate base first, it would be desirable that all data be registered as closely as possible to a standard geographic coordinate system (universe transverse Mercator). This is preferred for several reasons (geometric properties, and existing map). If the raw data could be registered accurately to a geographic coordinate system, this would automatically take care of both cases. However, the problem of achieving this is extremely difficult and probably too expensive to solve with the current state of technology.

Many users will be able to accept relatively poor geometric accuracy. However, there are a number of users working in the digital domain that will require very precisely registered data from pass-to-pass within the same track or between the adjacent tracks. For this purpose we recommend 0.5 picture element overlay accuracy. This level of accuracy is needed to achieve the classification accuracies required by the user when the data is processed in a multitemporal mode.

Relief Displacement

Relief displacement becomes a very significant problem as the angle from the nadir increases. Figure 1 relates the picture element displacement, terrain height and angle from nadir to the pixel. Even in low terrain a local change in elevation will cause significant displacement of pixels. In 250-foot (76-meter) terrain with an off-nadir angle of 22 degrees, a one picture element shift in location from true position will occur. In terrain commonly found in areas of high interest (2500 feet, 762 meters) picture element displacement will be slightly greater than 10 elements. Reducing the angle to 7.6 degrees, the extreme found in a vertically oriented thematic mapper at an altitude

Figure 1. Effect of Off Angle on Pixel Displacement Due to Terrain.



where Δh is difference in terrain height.

of 714 kilometers, the displacement is less than one-half picture element in the low terrain (250 feet) and slightly over three picture elements in the 2500-foot terrain. In the western United States 5000-foot terrain (1524 meters) changes are the normal. This causes a 20-picture element displacement at 22 degrees and a 6.5 picture element displacement at 7.6 degrees. It should also be noted that a conical scanner will have a constant 7.6-degree angle from the nadir, creating the worst case in relief displacement for all the picture elements because of this constant angle from the nadir.

TEMPORAL FREQUENCY OF OBSERVATIONS

There are a number of factors that influence the desired frequency or optimum frequency of temporal coverage.

(1) The short and long term correlation of cloud coverage causing high percentages of cloud cover on imagery.

(2) The phenomena that require repeated coverage over a short period of time to detect change in vegetation phenology.

(3) The need to obtain data at critical points in the crop or vegetation cycle such as planting, drying, harvest.

(4) Allow for a more timely publication (release of summary information to have maximum impact on the potential user).

(5) Provide useful data for disaster assessment such as flood, fire, etc.

The maximum repeat cycle would be nine days with a four to five day repeat cycle even better. Very short repeat cycles, one to two days, are required to satisfy (5) above, but cannot be cost effectively obtained without a multiple satellite system and a high throughput rate in ground processing. Therefore this type of coverage would be sacrificed for economy's sake and practicality. The panel prefers the two-satellite narrow swath width option. In one satellite system a wide swath width creates a number of problems associated with geometric fidelity and atmospheric effects. The wide swath width option provides the worst case in relief displacement, causing unacceptable local displacements of picture elements due to the terrain effect. The wide swath width also creates the worst case for atmospheric effects on the radiometric quality and geometric quality of the image. A wider swath width created by reducing the amount of oversampling should be considered as an option to the 0.4 oversampling system. currently on LANDSAT I and II.

In order to determine the optimum period of coverage we need more information on cloud cover, periodicity and day-to-day correlation of cloud cover. The studies available to the panel are in conflict. One study indicates a very low day-to-day correlation, while another study indicates a high day-to-day correlation. A number of investigators indicated that there seemed to be a very high day-to-day correlation. In other words, if you had clear coverage one day, the next day pass would be clear, or conversely, if you had cloud cover one day, you could expect cloud cover the next. This was based on a number of investigators searching imagery for cloud coverage. for specific projects. It was not quantitative, but more intuitive.

Another question directly related to the period is the timing of the dissemination of information. There are a number of users that can stand delays of several weeks because the phenomena they are investigating or observing is not that dynamic. However, users interested in disaster assessment, agricultural productivity and change detection in general require relatively quick turnaround times. The opinion was stated that an eight-day turnaround time was the maximum allowable, with a minimum turnaround of 48 hours.

The Time of Day of the Coverage.

The cloud cover pattern affecting the time of day of image acquisition seemed to be even less well documented. Because of the existence of the thermal channel on the system a 11-o'clock time appeared to be optimum based on the probability of cloud coverage and the development of the thermal patterns in the surface cover. It was generally agreed that the later times would be better in terms of the thermal information but that the problems of cloud cover and the cooling of the sensor array made a later time unfeasible. It is recommended that the cloud cover built up during the day be studied carefully for the agricultural areas of high interest to determine the optimum time of acquisition.

Image Data Spatial Sampling Schemes

It is widely recognized that sampling is necessary to achieve effective along-track resolution equivalent to the cross-track resolution. However, the panel is not convinced that a spatial sampling rate of 1.4 IFOV (along scan lines) is the appropriate value to achieve this goal and recommends a more thorough study. Careful consideration of this problem is worthwhile in the following sense: if the sampling rate of less than 1.4 IFOV will provide equivalent along-track resolution, it would be possible to go to a lower data transmission rate or trade off some of the picture element to picture element overlap for increased swath rate without sacrificing radiometric or spatial resolution. If the sampling rate should be greater than 1.4 IFOV, the specifications must reflect this to obtain equivalent along-track resolution.

CONICAL VERSUS RECTILINEAL SCANNER

Except for the bad experience with the Skylab S192 system including the ground processing, the panel has no strong rationale for selecting one type of scanner over the other. However, whichever type of scanner is selected, the total system must be designed to meet the band-to-band registration, the image-to-image registration, the signal-to-noise, the spatial resolution and the atmospheric effect specified in the stock unit. Although there is no strong evidence to indicate that the following problems cannot be overcome, some of the problems that would make a conical scanner unacceptable are listed below. The effective ground coverage of a picture element is affected by the forward motion of the scanner on one side of the spacecraft versus the rearward motion of the scanner on the other side. With the sensor array proposed for the thematic mapper this has little effect (0.3%) but if slower scan speeds are used, this problem could become significant. A problem is posed by the fact that the reflectance from most targets is anisotropic in three dimensions. Thus, the sun angle is an important "driver"; next in importance is the sensor angle off the nadir. With a rectilinear scanner the angular relationship between the sun and scanning instrument is minimized and simplest. With the conical scanner, the relationship is much more difficult to determine and may have serious effects on the spectral fidelity of the system. The correction for this phenomena in a rectilinear scanner is one-dimensional; with the conical scanner the correctional problem is two-dimensional.

As stated before, the conical scanner provides a constant worst case image acquisition system in terms of relief displacement. With a constant 7.6-degree angle from the nadir, the picture elements are being moved not in relation to a scan line, but radially from the nadir point. The compounding of the large angle from nadir and the radial displacement would make the problem of geometric correction and image-to-image overlay extremely difficult.

THERMAL CHANNEL RESOLUTION

Thermal at the same resolution as the other bands would be ideal. However, the multiple of three will be acceptable. This will place one element from each band in the center of the thermal element which will undoubtedly provide additional useful information to investigators using the thermal bands.

ERTS MSS on the Same Mission

The panel believes that it would not be necessary to fly an ERTS multispectral scanner on the same spacecraft as the thematic mapper. An ERTS pseudo-image can be produced from the proposed bands. The users that will be most interested in using the ERTS-type image will undoubtedly be the photointerpreters and they will probably be unable to tell the difference between the thematic mapper pseudo-image and an actual ERTS image except for the increased spatial resolution. The users that will be most affected by the change (digital processing) will be the most prepared and most interested in handling the upgraded spatial and spectral images available from the thematic mapper and will probably have little interest in continuing to process the ERTS-type MSS data.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1975—671-548/37