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Final Report: National Science Foundation Remote Sensing Workshop. Held at Purdue University February 28, 29, March 1, 1984

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Laboratory for
Applications of Remote Sensing
and

School of Electrical Engineering
Purdue University
West Lafayette, Indiana 47907

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FINAL REPORT

NATIONAL SCIENCE FOUNDATION REMOTE SENSING WORKSHOP

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PURDUE UNIVERSITY
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PREFACE

It was the purpose of this workshop to examine the potential for further advancement of the science of remote sensing, and to define directions which the Engineering aspects of remote sensing research could not take in order to maximize the scientific and technological return.

The modern era of the field of Earth Observational Remote Sensing began in the 1960's when computer-based techniques were added to the already well established photographic techniques. This new branch of the science brought with it fundamentally new concepts. These new concepts were drawn from the results of research which had accumulated to that time in such diverse fields as solid state electronics, pattern recognition, communication, and computer engineering. A very effective research program to draw out the needed new concepts and mold them and extend them to the needs of Remote Sensing very quickly resulted in several major new milestones of the field.

This new branch of Remote Sensing resulted from the convergence of the emerging capability to operate in Earth orbit with the rapidly developing ability to compute and to handle large quantities of data in quantitative form. First, there began the (initially rather crude) observation of the weather with its modest requirements on spatial resolution and reflected energy measurement precision but the significant need for frequent observations; there followed the steady refining of these abilities to both collect higher quality data and to better understand the data collected. After a dozen or so years, the ability to observe the land was added as well, with its reduced need for frequent observations but greater need for finer resolution in both the spatial and spectral sense.

Earth Observational Remote Sensing must now be seen as both a science and an application. It is a science in the same sense as, for example, astronomy or planetary geology. It is more than simply a tool for observation of a specific planet; one has only to review the subject matter of the various journals or symposia devoted to it to become aware of this. Rather, it is an interdisciplinary field involving the harmonious, integrated functioning of Engineering researchers who are learning how to produce effective observational information systems with portions of the Earth Science research community who are studying both local and global Earth processes as a matter of basic science.

Remote Sensing is not only an interdisciplinary field, but as a science it spans the spectrum from basic research to operational use. This path from new concept to operational use is diagrammed in Figure 1. Beginning with new knowledge accumulated in various other disciplines, a capability to collect and analyze data remotely must be created. With this capability a more thorough understanding of the scene from a Remote Sensing standpoint can be created. These two then form the raw material from which a useful application can be studied and turned eventually into an operational facility.

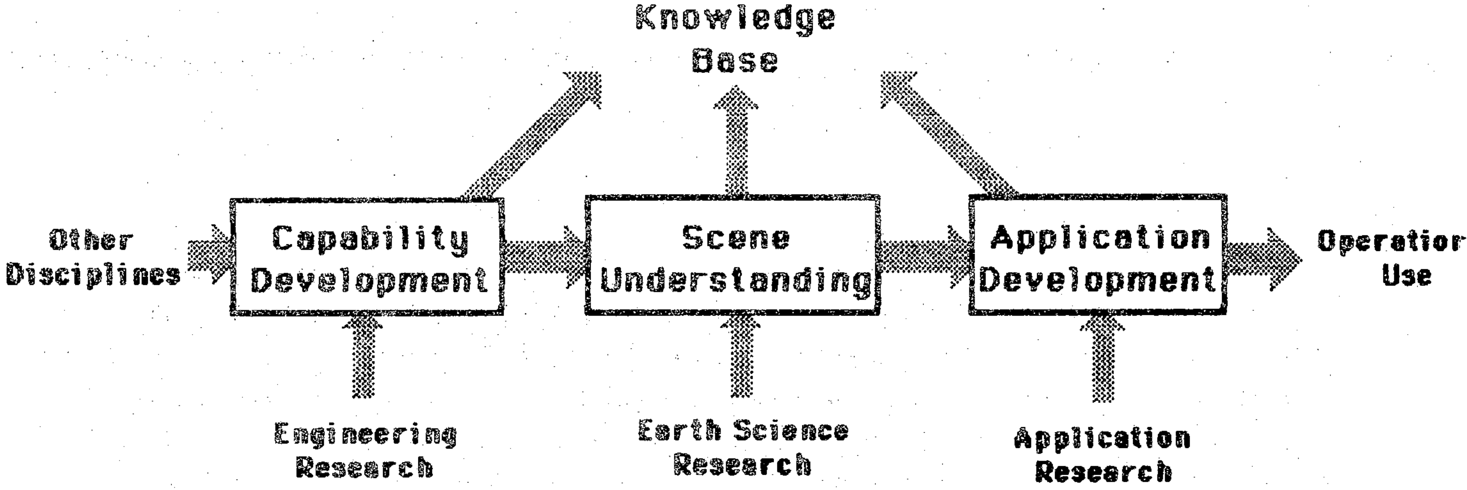

Figure 1. The research spectrum in Remote Sensing.

However, at least as important in the longer view is the fact that this process also must and does contribute to our knowledge base about the Earth, its condition, its processes, and how information about them may be obtained. It is this function, a recently more widely recognized one, which is in need of sustained attention, for its potential benefits for both science and application are substantial.

Along the way in this process of Figure 1, first Engineering researchers, then Earth Scientists, then application researchers are seen to play key roles, but it must be emphasized that (a) progress is maximized if an interdisciplinary team of all of these types of researches is used, and (b) the process is not really a strictly sequential one as might be first inferred from this diagram. Rather, it should be an iterative process with strong feedback. Though the workshop was centered upon the Engineering aspects of Remote Sensing, recognition of the importance of this feedback and of this interdisciplinary nature was assured by having earth and application scientists, as well as engineers, as participants.

The concentration since the early 1970's on applying the then existing knowledge has meant that in the intervening years a new accumulation of knowledge has taken place in the other related disciplines which may now be taken advantage of. Thus there are, no doubt, adequate "raw materials" for significant new advancements in the field. Further, there are a number of additional institutional factors which are beginning to shape the future of the field; we will mention three in particular here.

First we must cite the commercialization of Landsat, and the whole issue of who will operate operational systems. At this writing it seems at least likely that operational land observing satellites will indeed be operated by a private entity, and atmosphere and ocean observing systems will be in the hands of NOAA. It seems *highly unlikely* that a private entity will conduct all of the types of research indicated above, and if current budget trends are any indication, the same may be true of NOAA, U.S. Department of Interior, and the other, more mission-related agencies of the federal government.

The second major factor to be mentioned is a developing earth and application science thrust to use Remote Sensing to study the Earth as a single integrated system. Based upon a completed National Academy of Sciences study and one in process by a NASA advisory committee, a program to use Remote Sensing in this way to generate new knowledge about how the Earth processes function on a global scale is now feasible by building upon existing capabilities. This would indeed be a very large undertaking and will require a number of advancements in knowledge of a fundamental nature. It is a reasonable expectation that NSF will need to play a role in this effort as only NSF has the proper infrastructure to bring about some of the advancements needed.

The third major factor is the planning of the Space Station. At this time, it seems likely that a permanently occupied station and co-orbiting platforms in a near equatorial orbit, and one or more platforms in a sun-synchronous near polar orbit seem like a reachable goal by 1992. This Space Station is not being designed for a specific mission, as most earth satellites of the past. Rather, it is being designed as a broad purpose facility located in space to take advantage of the unique vantage point and environment present there. It thus represents a wholly new type of laboratory in which to conduct research experiments. Clearly, it will provide unique opportunities for Remote Sensing experimentation, both fundamental and applied.

All three of these factors point to a clear need for a well devised program of research in Remote Sensing. Much of it will need to be applied in character, which is a type inappropriate for conduct by NSF. Much of it more basic but primarily in the Earth Sciences. Clearly, however, there is the need for important new work in the Engineering aspects of Remote Sensing.

Research of a more fundamental nature requires a maximum of creativity; it is, no doubt, for this reason that NSF, for example, relies exclusively upon an unsolicited rather than a solicited proposal procedure. For this same reason, we have tried to avoid saying what research tasks should be done; rather we have attempted to perceive directions which seem fruitful and to sense trends which seem to be occurring and some of the forces driving them. It remains for the creativity of individual researchers to proposed specific studies. It is hoped that in doing so, this report of the NSF Workshop on the Engineering Aspects of Remote Sensing will make a significant contribution to the National Foundation towards the structuring of its part in the upcoming national effort in this field.

D.A.L., September 1984

This report contains recommendations to the National Science Foundation by a non-government group and should not be constructed as a statement of official NSF policy.

FINAL REPORT

NSF REMOTE SENSING WORKSHOP
Purdue University
February 28, 29, March 1, 1984

I. WORKSHOP OBJECTIVE AND ORGANIZATION

Remote Sensing is a very old science and art. Depending on how liberal one wishes to be with its definition, it can be said to go back decades, centuries, or millennia. However, over the last two decades, great advances have been made, principally as the result of incorporating into the field new developments from a number of other technological fields. Among these fields are sensor and detector technology, optics, microwaves and radar, communication and information transmission, and a large variety of data manipulation and information extraction technologies. It has thus become an inherently interdisciplinary field, not only in its application but in its technology base. Thus, while it has at one end long been tied to a variety of application discipline fields, it has, at the other end, become tied more recently to a number of more fundamental engineering and science disciplines.

During this same period, remote sensing has become much more valuable and useful, perhaps even indispensable to mankind. This has occurred in part because of these recent advances in the state of the science and art of remote sensing, but also because of the growth in mankind's perception of the limitations of the Earth's resources and the approach to these limitations in a number of areas.

It is thus most appropriate that from time to time groups of engineers and scientists should be brought together to consider what the state of the development is, and what directions this development should take next. A remarkable degree of advancement has been achieved in the past two decades by choosing lines of research based upon advances in more fundamental sciences; it now seems obvious that such strides can continue if one carefully continues this process.

This particular workshop was intended to be appropriately modest in its breadth and duration, focusing on the *engineering aspects* of remote sensing and lasting two and one half days. The main body of the proposal to NSF upon which the workshop was based contains further definition and rationale for it, and is included as Appendix A. Researchers were invited to participate based upon their scientific credentials and the desire to achieve a suitable sampling of the spectrum of engineering disciplines which appear likely to be significant to remote sensing in the coming decades. Many, indeed most, have had lengthy experience in remote sensing research; some, however, were selected because they are experienced in fields new or likely to become important to remote sensing research. The list of attendees is contained in Appendix B of this report.

The planned schedule for the Workshop is presented in Appendix C. The basic plan was to treat the subject matter by addressing three broad areas. Within each area speakers were invited to make related presentations in order to provide a focus or point of departure for discussion and to bring out many of the topics which might be expected to emerge. This was to be followed by a brief plenary discussion and then the retiring to smaller working groups in which it would be possible to hear from a greater portion of the group.

The first of the three areas, a discussion of the ultimate potential information content of sensible force fields existing at satellite altitudes above the Earth, and the features of these force fields which make the information sensible and extractable, was intended to provide a broad and long range perspective of the field. After this, the more focused and specific subjects of sensor systems and data processing were addressed.

The working groups were purposely chosen to be similarly constituted. That is, instead of having all of the sensor people in one group and the data processing people in another, they were as evenly mixed between groups as possible, thus permitting the examination of the potential of each part of the remote sensing system to be conducted in relation to the potential of the other parts. The late arrival of a number of the participants as the result of adverse travel conditions resulted in some revision of the order of events of the schedule, and, though it was originally planned to use three working groups, during the meeting it was decided to use two, thus saving reporting time by the working groups.

II. INTRODUCTION TO THE SUBJECT MATTER

As previously stated, this workshop was directed at the engineering aspects of remote sensing, meaning those aspects having to do with the technology of remote sensing, rather than its application disciplines. However, it is of essential importance that the designers of the technology must account for the proper influences of the use of the technology in its design. We will thus briefly mention the application context within which the workshop was conducted.

It has become common to define the application fields of remote sensing in terms of the

- Atmosphere
- Ocean
- Land

and that system of categorization was found suitable to our purposes. However, it is quickly recognized that a more detailed categorization is possible and common. For example, in the atmospheric case, subcategorizations of applications research and operations can be found according to geographic scale (micro, mezo, and macro-meteorology), time scale (modelling, forecasting, and climatology), and altitude. Land studies can be broken into those primarily related to the unvegetated Earth and the vegetated Earth; a further subcategorization leads to such disciplines as geology, soil science, etc., in the first case, and cultivated and uncultivated vegetation in the second. From there one proceeds to agronomy, biology, ecosystems, forestry, range science, etc. Ocean applications have many of the same types of subcategorizations as the Atmosphere and Land, including significant physical linkages to both.

We wish thus to draw attention to and to indicate a recognition of the diverse breadth of applications which must somehow be accommodated in the technology research. Though the experience base represented in the participants to this workshop could not be detailed enough to cover each of the possible subdisciplines of these applications fields, there was at least some representation of each of the three major application categories mentioned above.

Having raised the matter of applications, it is useful to point out in more complete terms what are proper motivators or drivers for pursuing remote sensing research. Such drivers can be divided into two categories:

- Use Drivers - What does the user need?
- Possibility Drivers - What can advancements in the related sciences allow?

As far as remote sensing technology is concerned, both applications research and operational remote sensing fall in the former category; by studying the user community and listening to the needs as expressed by its practitioners, one can find a considerable variety of stimuli for research. This source of stimuli has been the dominant one of the past several years. It is certainly a logical one and a conservative one, for there would appear to be little risk in choosing research topics based upon a previously identified need for the expected products of the research.

On the other hand, choosing research topics based upon what is known to be needed can make for slow progress, because, while it insures that a solution will be useful, it does not ensure that it will be easy to obtain or even possible. Possibility driven research tends to have the opposite characteristics. The results are often not predictable but may come quickly and with less cost; they may be expected to be more frequently of the breakthrough nature. As a result of remote sensing research of the recent past primarily taking its cue from the user, it was felt desirable in this workshop to provide somewhat greater emphasis to possibilities suggested by recent advances in the more fundamental sciences and technologies.

It is also useful to have a working hypothesis as to where the total development of remote sensing systems is in its overall life. How near to fully developed does it appear that the technology is? The following is taken as a basic hypothesis on this point:

> Though much progress has been made, the *full potential* of the aerospace vantage point for the purpose of gathering information about the Earth and its natural and man-made processes *has not yet been envisioned, let along realized.*

In other words, given this hypothesis, we can take the further potential for development of the field as not a limiting factor; the possibility for further development of this technology is enormous.

Having stated an applications frame of reference, having discussed the motivations for such research, and having stated our hypothesis regarding the potential for further development, we now turn to a suitable systems framework within which to consider the directions for such further development. At this point, the specific form and details of this systems framework are not so significant; that form and those details are, after all, what the research is supposed to produce. What is significant is that there be such a systems framework concept operative so that as work proceeds with regard to sensors or information extraction algorithms or any other element of the system, it does so in relation to possible developments for the rest of the system which that element can support. The overall systems concept displayed in Figure 1 is presented as such a frame of reference here.

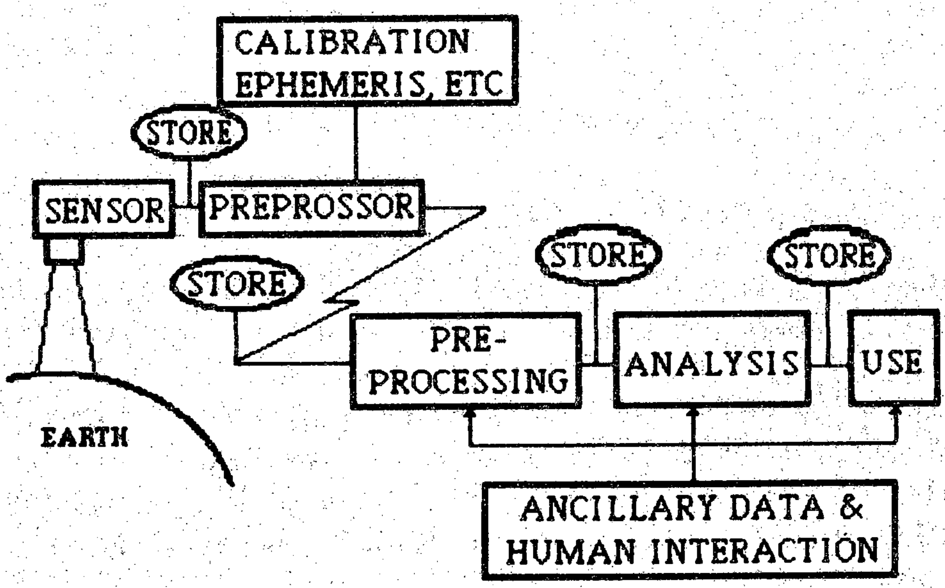

Figure 1. Remote Sensing Systems Concept

Thus one has a sensor, either active or passive, viewing the surface of the Earth. There may be the need for some on-board processing, perhaps including both geometric and radiometric adjustments, calibration, the insertion of pointing or ephemeral data into the data stream, and the implementation of data compression and preliminary data reduction techniques. The data might then be transmitted to a ground station via suitable telemetry where further preprocessing would be conducted, followed by the application of perhaps many analysis and information extraction algorithms. During the course of these processes, ancillary or correlative data may be merged with the data stream, no doubt including human interaction with the data and the algorithms.

In preparing to study the further development of such a system, it is useful to parameterize the system so that potential research thrusts can be conveniently related to it. In order to do that, notice the points at which information in some form either enters or leaves the system. It is a well accepted fundamental so far as the sensor is concerned that the information at the sensor aperture is contained in the spectral, spatial, and temporal variations of the force fields entering the aperture. The other points of information transfer to or from the system are at the entry of the ancillary data and delivery of information to the user. In addition, one must account for internal noise sources as they affect the net amount of information available at any point. Thus the following list of system parameter categories can be used as an exhaustive set:

- Spectral Sampling Scheme
- Spatial Sampling Scheme
- Temporal Sampling Scheme
- Signal-to-Noise Characteristics
- Ancillary Data
- Information Produced

Even though the workshop was not directed at applications, it is appropriate to consider the economic implications of any proposed research directions. To illustrate how economic implications properly impact such studies, first note that there are trade-offs among the system parameter categories. For example, in order to increase the spatial resolution of an optical sensor either the spectral resolution, the dwell time (temporal sampling parameter) or the signal-to-noise characteristics will need to provide some relief, since the net amount of energy available to sense is fixed. In such sensors, it may generally be true that spatial resolution is expensive to obtain, since increased spatial resolution usually requires physically larger optics, making the spacecraft larger and heavier. It may also lead to more stringent attitude control specifications to achieve proper pointing characteristics, and the volume of data generally goes up as the square of the spatial resolution, thus increasing the costs in the data handling and processing portions of the system.

Another, more global type of economic consideration which further illustrates the point resides in the following. It has already been stated that there are a wide variety of applications and users who might wish to take advantage of this technology. It would be very desirable from a design standpoint if different systems could be constructed for each different application; then the design and operation of each system could be optimized over a much smaller set of variables. However, this is probably not reasonable from a cost standpoint, and in order to achieve a high number of users per system and thus a greater apparent cost/effectiveness, one must accept the limitations on optimality which this diversity will require.

We mention in passing that this diversity of uses also raises an interesting technical question, namely how does one optimally design a system for so broad a class of uses? For example, if one were required to design an optical satellite sensor for the purpose of forest data acquisition, then the selection of spatial resolution could be carried out in relation to the dimension of trees as seen from above, the spectral bands could be chosen based on the spectral response of expected tree species and non-forest surface cover in forest surroundings, the orbit in relation to the needed temporal sampling frequency for forests, and so on. However, for a satellite which must serve all of the land Earth surface disciplines, it is perhaps less clear how to proceed with the design, and what the price in optimality will be.

Proceeding one step further in detailing the illustration, in the case of the more application-specific forest satellite above, the design philosophy might be based on optimality in terms of the information desired by the user. However, in the latter, general purpose sensor system, the diversity of information desired makes such a design philosophy of questionable value. An alternative design philosophy which might be more applicable would be to design each system element to maximize the total information flow through the system. In this case one would view the system in terms of the information flow passing each point, and the sensor, the preprocessors, the analysis system, etc., would be seen as transducers, merely changing the form in which the information exists.

A key design question then becomes, how does one define information and thus determine if a candidate sensor system is well designed by the maximum information flow standard. That is, how does one determine that all (or nearly all) of the information still exists in electrical form at the sensor output that existed in optical form at its input? One requires an information measure which is itself generic and not application-related. One (very conservative) approach to optimizing the degree to which this is the case is to design the sensor system for what might be called maximum invertibility. That is, to what extent would it be possible to reconstruct the input to the sensor system from the signals at the output? This *maximum invertibility property* is one which could be converted into a mathematical form suitable for design purposes, thus providing a practical basis for optimal design.

Obviously there are many conjectures contained in this illustration which need verification; however, its intent of serving to illustrate matters which need attention in the research selection process and in the conduct of research is, we trust, apparent.

III. SENSORS: STATUS, DIRECTIONS, AND RECOMMENDATIONS OVERVIEW

The overall development of remote sensing technology has been closely related to that of sensor technology. Early in the workshop there was discussion that the choices of remote sensing technology development should be based not only on user need, but upon providing new capability made possible by advancing technology as well. The reasoning for this is that the user is not always in a position to perceive what is possible in the sensor areas, and thus relying too heavily upon his stated needs may result in some substantial breakthrough advancements being missed.

It was also argued that the nature of the field is to build fundamental capability which, as experimental apparatus, can last a long time because it undergoes continual improvement. The example of the Mt. Palomar optical telescope was cited. It represented an enormous fundamental capability from the day it was first used, but this capability has been steadily increased over the years with improved auxiliary equipment.

One consensus reached in the workshop is that sensor capability is a technology driver for the field, and that *sensor development is often a trigger to fundamental advancements in remote sensing technology.* Indeed, such advancements often stimulate an increase in what the user specifies as a need. The current malaise in the national remote sensing program may, in part, be due to a stagnation of sensor research in the U.S. national program. The building of a capability beyond currently perceived needs may, indeed, be a sound research philosophy.

Another consensus reached is that it is not appropriate to talk of optical versus microwave, but optical *and* microwave. The integration of optical and microwave sensors will be a critical part of the remote sensing systems of the 90's and beyond. It is now practical to develop such systems, although the fundamental understanding of data from such a combined system is not yet developed.

Several times during the workshop, it was noted that the U.S. has apparently lost its leadership role in remote sensing technology. The next generation of space-borne scanners using advanced array technology is to be launched by France and Germany. The U.S. research landscape seems to be littered with the debris of canceled advanced scanner programs. Several U.S. scanner studies were listed that wound up as reports rather than instruments. The lack of a strong aircraft research scanner program was also noted. Several landmark results in the early days of remote sensing were obtained using data that were acquired with aircraft under carefully controlled conditions, a difficult procedure with spacecraft data.

The consensus was that optical scanner design will emphasize large numbers of narrow spectral bands and spatial resolution of contemporary scanners. Pointable imagers were considered to be an attractive concept. High resolution synthetic aperture microwave scanners with multispectral capability were felt to be valuable, especially if integrated with optical scanners. There was considerable discussion on the need for basic work in scene-radiation interaction and its effect on sensor design and data processing techniques.

OPTICAL SENSOR EVOLUTION AND RECOMMENDATIONS

Dr. Warren Hovis presented the principal paper (see Appendix E) on optical scanner evolution and research recommendations. The evolution of the Landsat four- (and five-) band scanner, MSS, was traced, as was that of the seven-band Thematic Mapper (TM) scanner. The relatively wide spectral bandwidth of these scanners was dictated by both technical design considerations and the perceived need for wide bandwidths. The shape of the spectral responses of the MSS and TM were less than ideal and future designs should emphasize controlled optimum or rectangular response. It was agreed that the TM represents the design limit for a vibrating-mirror scanner. Also the data-rate requirements of the TM (85 megabit/sec) will crowd the state-of-the-art for some time to come. The evolution of several self-scanning array sensors was traced through some design studies in the U.S. that have culminated in two soon-to-be operational scanners in France and Japan.

In 1972 two instruments, the High Resolution Pointable Imager (HRPI) and the High Resolution Imaging Instrument (HRV), were proposed. The HRPI had a spatial resolution of 10m, a swath width of 48km, and four MSS-like spectral bands. It was capable of off-nadir viewing of 10 degrees in 1 degree steps. The HRV had a spatial resolution of 20m in the multispectral mode and 10m in the panchromatic mode. It had a swath width of 60km (if two sensors were overlapped the swath width would be 117km). It had the spectral coverage of the first three bands of MSS and could be pointed off nadir up to 27 degrees in 0.6 degree steps. The scanner could be spectrally reconfigured to cover most of the visible wavelength region in a panchromatic mode. Neither of these sensors was ever built and launched into orbit.

The Multispectral Electronic Self Scanning Radiometer (MESSR) was described that has roughly the same spectral coverage of the MSS but with a spatial resolution of 50m and a swath width of 100km. This scanner is being constructed by Japan and is scheduled for launch in 1985 or 1986. The design is based on that of the U.S. Multispectral Resource Sampler (MRS) which was proposed but never built. The French System for Observation of the Earth (SPOT) which resembles the MESSR was also discussed. The SPOT is under construction and is scheduled for launch in 1986.

The discussion then turned to the NASA Linear Array Scanner (LAS) that has six spectral channels in the visible and short-wave infrared. It has spatial resolutions of

15m and 30m with a swath width of 30km. The scanner is currently under construction and would be launched on the Shuttle at the end of 1987 with data transmission via the TDRSS satellite (42 megabit/sec) if the project funding is continued.

The NOAA and NOAA-NEXT imagers that have spectral bands in the visible, short-wave infrared, and thermal infrared with spatial resolutions of 1.1km were discussed. The geosynchronous satellites GOES and GOES-NEXT that also have spectral bands in the visible, short-wave infrared and thermal infrared with spatial resolutions of 1km, 4km, 8km and 10km were discussed. The GOES satellites are capable of both sounding and imaging (sounding and imaging can be done concurrently on GOES-NEXT).

The importance of calibration in future sensor designs was emphasized. The calibration schemes used on the MSS and the Coastal Zone Color Scanner were described and discussed. The importance of well-founded calibration of data to the assessment of data quality and the evaluation of instrument condition was pointed out. Several examples were shown and discussed of how calibration data were used to track instrument condition. Strong recommendations were made for the support of research into improved methods of instrument calibration. It was also recommended that scanners have provision for electronically variable spectral bandwidth and spectral configuration as well as electronically variable spatial resolution so as to fit sensor capability to particular applications.

There was a discussion on the possibility of a geosynchronous high resolution imaging satellite. The results of calculations were shown concerning a satellite in a 38,000km geosynchronous orbit with a diffraction-limited resolution of 10m (at a wavelength of 500nm) with a system modulation transfer function of 0.2 and a telescope obscuration of 20 percent. Such a scanner would require a telescope diameter of 200cm. This is not altogether unreasonable since mirror (or other scanning devices) scan rates would be quite slow at those altitudes. If the spatial resolution were reduced to 50m the telescope size would be approximately 40cm, about that of the TM. Also the data rates would be much more reasonable than those of satellites in near polar orbits. The disadvantage of large spacecraft-target distance in a geosynchronous system as compared to a 900km polar orbit, is overcome with the longer scan time that is available. The geosynchronous satellites could be moved in their orbit positions, according to the season of the year, so as to effectively widen their area coverage. Such techniques are used in the GOES system. The geosynchronous approach would enable the acquisition of cloud free data with relative ease in the optical wavelength regions. Data overlay is also facilitated.

MICROWAVE SENSOR EVOLUTION AND RECOMMENDATIONS

The principal paper on microwave sensors was presented by Dr. Keith Carver (see Appendix F). The characteristics of scatterometers, scanning radar altimeters, bistatic radar systems, and synthetic aperture radars (SAR) were reviewed. The evolution of spaceborne SAR from Seasat through the three shuttle imaging radars (SIR-A, SIR-B, and SIR-C) and EOS was traced. The Seasat flew in 1978, and SIR-A in 1981. SIR-B is scheduled in October, 1984 and SIR-C in early 1987. EOS is postulated for the mid 1990's and would be equipped with multi-sensors and an advanced SAR.

The principles of SAR were reviewed and the technology drivers of spaceborne imaging sensors were discussed. The sensor drivers are sensitivity, calibration, and parameter flexibility. The data drivers are A/D conversion, data rates, data storage, and data processing. The spacecraft drivers are prime power, heat transfer, and sensor deployment. The power requirements of active microwave systems were discussed. The average power requirements range from 50W for a like-polarized system operating at 1GHz with an inclination angle of 20 degrees to 40kW for a cross-polarized system operating at 10GHz with an inclination angle of 50 degrees. The Seasat, SIR-A, and SIR-B are examples of 50W average power systems. Candidate transmitter designs for L-band and C-band are paralleled, solid-state power amplifiers or distributed, gallium arsenide, field-effect transistor hybrid or monolithic technology. For X-band distributed, gallium arsenide, field-effect transistor hybrid or monolithic technology would be required. Over 10,000 modules may be required for a high power system. It would require a major development effort to produce such a system. Another possibility for X-band would be high-power pulsed traveling-wave tube amplifiers, but these are heavy and require high voltage power supplies. All designs would have to be space qualified with three to five year lifetimes.

The technological challenges for future SAR systems fall into four basic areas: data transmitters, spacecraft resources, and antennas. The data challenges are very high-speed, high-resolution A/D converters, ultra wideband data relay satellites, and real-time, on-board image processors. The transmitter challenges are high-power, space-qualified transmitters and monolithic transmit/receive modules for distributed SAR. The spacecraft resource challenges are high-power ($>$ 10kW) prime power sources, advanced space materials, and novel designs for large space structures. The antenna challenges are array and reflector designs for large spaceborne SAR antennas, precision surface tolerance technology, multi-frequency antenna designs, and electronically beam-scanned SAR.

It was suggested that the spaceborne imaging sensors of the 1990's would have both optical and microwave components. Microwave sensors should have L-, C-, and X-bands and optical sensors should have visible/near IR (.45um to 1um), short-wave IR (1um to 2um) and thermal IR (10um to 12um) bands. The active microwave (synthetic aperture) sensors should have a spatial resolution of 10m to 25m, the passive microwave radiometers a spatial resolution of 100m to 10km, the thermal IR sensors a spatial resolution of 50m to 100m, the short-wave IR sensors a spatial resolution of 10m to 25m, and the visible/near IR sensors a spatial resolution of 10m to 25m. The swath coverage of the satellites should be determined principally by the user community. Practical swath widths for synthetic aperture radar are from 50km to 200km.

SUMMARY OF SENSOR RELATED RESEARCH RECOMMENDATIONS

We list here as specific recommendations only what appear to be the highest priority research topics of all those discussed.

RECOMMENDED PRIORITY RESEARCH TOPICS

1. ADVANCEMENTS IN OPTICAL SENSORS

Sensors with large number of narrow spectral bands.
Study of off nadir pointing and of polarization effects.
Advances in sensor precision and calibration techniques.

2. ADVANCEMENTS IN MICROWAVE SENSORS

Multifrequency, electronically scanned Radar.
High efficiency solid state transmitters and distributed SAR designs.

Implied within these or in some cases in addition to these are a long list of additional needed research topics. These include improved detectors, spectral filters, and detector coolers; active optical alignment systems; high speed spaceborne data systems; and advances in basic sensor/scene interaction physics. It also is appropriate to begin studying means for producing both optical and microwave multiband imaging spectrometers capable of high spatial resolution from geosynchronous orbit.

IV. DATA PROCESSING: STATUS, DIRECTIONS, AND RECOMMENDATIONS

Remote sensing as a science and technology has matured to the point where it no longer stands alone. It has been recognized that remote sensing is most usefully viewed as just one component, one tool, of the complex now often called "geobased information systems." It was in this context that the workshop attendees tackled matters relating to the computer processing and storage of remotely sensed data.

Two excellent papers were presented to the workshop session on data processing methods and systems. Dr. R. M. Haralick described his research involving the emulation of an image interpreter faced with the task of deriving terrain information from a single multispectral image. His talk (see Appendix G) demonstrated the power of spatial reasoning processes of which the human is capable and which have yet to be cast in computer algorithms.

Dr. H. Freeman presented his work on automating the labeling of map features, including point, line and area features (see Appendix H). Here again higher level reasoning is required which involves nontrivial spatial relationships.

From these stimulating presentations, the working groups headed off into as yet uncharted territories where they raised a myriad of data processing issues related to hardware, software and algorithm research needed to support the future development and application of remote sensing and geobased information systems.

STATUS

"Per-Pixel" Classification

Classification of multispectral data on a pixel-by-pixel basis has been widely exploited. Statistical decision theory in many forms has been applied to provide optimal classification of the spectral measurement vectors. Feature extraction research has provided useful methods for obtaining effective features of reduced dimensionality, such as linear combinations and ratios of the spectral bands, to make feasible the classification of large volumes of multispectral, sometimes multitemporal, data.

One of the difficult problems as yet unsolved is how to deal effectively with "mixture pixels," pixels consisting of sub-pixel areas of multiple cover types, often on the edges of homogeneous areas. Given a sufficient number of spectral measurements on such pixels, they may, in theory, be decomposed into their component cover types. In practice, however, circumstances and computational restrictions do not allow such a straightforward solution. Because so much of a typical scene is composed of mixture pixels, this constitutes an important practical problem. It is likely an unsolvable one on a pixel-by-pixel basis.

Spatial Information

Beyond the spectral domain, methods for characterizing and extracting spatial information from image data have been successful, although mostly on a local, rather than global, basis. The statistical classification methods have been extended to classification of small neighborhoods using local contextual information. The properties which have probably received most attention are texture and shape. Many methods for characterizing texture are available and texture has been used successfully as an added feature in pixel-by-pixel classification to improve classification accuracy. Shape has mainly been used to distinguish small objects such as airplanes and military vehicles, usually without reference to multispectral characteristics of such objects.

On a somewhat less local basis, scene segmentation has been applied to partition a scene into "objects" followed by classification of the objects. But again the information used for the classification has been strictly of a local nature. Although some attempts have been made to apply more global syntactic and semantic information to remote sensing data, these have so far met with only very limited success in specialized applications. The effective use of global contextual information is viewed as an area of research with very great potential. The papers presented by Haralick and Freeman are representative in this respect.

Temporal Information

Multitemporal analysis has long been considered an important frontier for remote sensing research. Multitemporal classification of multipass Landsat data has proven quite valuable in agricultural applications. The most typical approach to this type of analysis is to use a feature vector consisting of spectral components selected from the available passes of the sensor. Sometimes linear transformations of these features are used to reduce the dimensionality of the data. Change detection in remote sensing imagery, another valuable form of information in such data, has been less successful. This is largely due to the extremely accurate registration of the different passes which this type of analysis requires, and also the fact that in change detection, errors tend to be additive over time (an error at any of the times a given pixel is observed results in an erroneous assessment of change at that pixel). Improvement in change detection methods remains an important area of research, one which likely will require considerations beyond the pixel-at-a-time viewpoint.

Multiple Sensor Data

Analysis of data from multiple sensors, both imaging and nonimaging, is an area yet to be fully exploited. Data from similar sensors, such as multispectral optical scanners aboard different vehicles, have been successfully registered and classified on a pixel-by-pixel basis. Images from radar have been registered with optical scanner data and analyzed to advantage in agricultural applications. However, as the sensor types become more disparate, there is correspondingly less understanding of how to best utilize their combined data conjointly. Even with radar and optical scanner data, there is felt to be much more information contained in their interaction than is currently being utilized.

Data Bases

The data base technology needed to fully support remote sensing and its applications is still in a fairly primitive state. Good progress has been achieved in image registration and rectification, although advances in sensor modeling would further enhance capabilities in this area. Also, moderately-large-volume data storage media are becoming available to store the massive amounts of data typically produced by remote sensor systems. However, research is still needed into memory organizations needed for most efficient storage and retrieval of large images. Also, it is not yet well understood how to deal with the great diversity of data types and formats which must be interfaced to each other and to the human data analyst. Simple extensions of conventional information management systems have not proven adequate.

Hardware

Digital image display systems have understandably become the chief medium for implementing the interface between the analyst and the multivariate remote sensing data. Dramatic advances have been made in this technology, paralleling developments in several associated technologies -- color image display media, digital storage devices and microprocessors. Special-purpose computer architecture development has also played an important role in the advancement of image display systems for remote sensing. The greatest need in this area now may simply be to bring the price of adequate systems down to where they will be more available to potential users. Further advances in digital system and device technology may be expected to meet this need in the future.

Because of its large degree of inherent parallelism, image processing has provided a fertile focus for computer architecture research, especially for those investigators interested in parallel architectures. So-called array processors have proven successful in applications of commercially available image processing systems. Highly parallel computer systems, including the ILLIAC-IV and STARAN computers, have provided demonstrations of the power of such systems for multispectral remote sensing image processing, showing that sufficient raw computer power can be made available to eliminate computational power as a fundamental limiting factor in the application of digital methods in remote sensing. Much of the ongoing research is in pursuit of effective methods for designing parallel versions of image processing algorithms and implementing them in parallel architectures. This challenging research problem has engaged many of the best computer scientists and engineers in the world.

FUTURE RESEARCH DIRECTIONS

We make the following observations:

1. The images acquired by remote sensing systems and the data bases in which they reside contain a great wealth of information as yet untapped.

2. A worthy objective for the science and technology of remote sensing and geobased information systems is to be capable of providing geo-information on demand -- as maps or in other forms -- in order to support decision-making processes to which they are relevant.

If one accepts these observations, a number of conclusions follow inevitably concerning some of the directions remote sensing research must pursue. To begin with, computer processing of remote sensing data and geobased data in general must be made capable of distilling information from a wide variety of data sources. It will be important for the user to be able to specify easily and precisely the nature of the information sought from the data. The processing systems must be able to provide this information rapidly and in a variety of forms and formats, both graphic and tabular. The information must be both accurate and current and must not require a considerable amount of additional interpretation to meet the need for which it was intended.

These requirements suggest some specific areas in need of attention.

Analytical Approaches and Tools

Pixel-by-pixel analysis of multispectral image data has been heavily exploited in the past, largely because the spectral domain has proven such a rich source of information about the nature of the ground cover. Recent advances in sensor technology have made possible the collection of images with significantly higher spectral dimensionality (literally hundreds of spectral bands), increasing the urgency for new methods for analyzing high-dimensional data.

But the discussions at this workshop emphasized that work should be focused beyond the pixel-oriented domain as well. By previous approaches it has not been possible to solve the "mixed pixel" problem and thus obtain, for example, subpixel accuracies in area measure. This is one example of a problem for which multipixel approaches may be useful. Another is the use of higher level reasoning, as illustrated by Haralick's emulation of a skilled photointerpreter; this is the kind of reasoning process which must be captured in computer algorithms in order to extract information from the available data sources and the complex relations among them. In a sense this is the goal of "image understanding" research, except that the reasoning processes must go beyond the spatial domain to deal with all aspects of the data environment. The methods of artificial intelligence are applicable, but a richer set of inference tools than the "if-then" construct of production systems is required. The "expert systems" approach to learning how people reason about complex data should be encouraged with respect to the remote sensing domain.

Some more fundamental analytical tools must be created or transplanted to the remote sensing domain. A "map algebra" is needed which can be used to express complex spatial relations as readily as linear algebra is used to relate multidimensional matrices. Some good beginnings have been made in this direction but much more remains to be done. Another tool mentioned as potentially useful is computational geometry. Dr. Freeman's presentation suggests a need to develop a kind of "computational aesthetics" in order to make acceptable maps by automatic methods.

Scene Models

Models are used in a variety of ways, to express concisely what we know about complex processes, to interpolate from observed phenomena, and to extrapolate or predict beyond such observations. More and better world models are needed in remote sensing for all of these uses.

Often mentioned in the workshop was the "invertibility problem," i.e., our frequent inability to recover a description of the phenomena which produced the observed measurements. This difficulty arises largely from our lack of understanding of the physical processes involved. Basic research is still needed to better model the interactions between electromagnetic radiation and Earth surface materials and the atmosphere. The results of such research will also provide a better understanding of how measurements from different sensors are related and which sensors are most likely to provide the kinds of information sought.

In addition to these "micro-models," "macro-models" of the natural and cultural processes which influence the makeup of the observed scene are needed for scene understanding. Relevant factors include climate and weather, topography and geology, agricultural practices and population trends, to name only a few. Of course, the temporal as well as geographic aspects of these factors are also important.

Computer Systems: Hardware

Many of the computer hardware needs of remote sensing are the same as in any other area requiring relatively large scale data processing -- more of everything from computational speed to memory capacity to I/O bandwidth. But there are also needs which are more specialized.

For example, the development of hybrid optical/digital computing methods could provide the speed of optical methods together with the stability of digital computation and convenience of digital programming. This would be immediately useful for implementing computations which have obvious optical analogs, including filtering transforms and the reconstruction of synthetic aperture radar imagery.

As noted earlier, parallel processing systems hold particular promise for image processing in general because of the inherent parallelism involved. However, several modes of parallelism are possible and there is a need to develop effective procedures for mapping parallel algorithms onto existing parallel architectures and, alternatively, specifying optimal architectures for given algorithms.

In the main, computer memories are constructed as one-dimensional entities whereas image data bases are multidimensional. Although high-level languages facilitate dealing with memory logically as though it were multidimensional, this may increase significantly the computational load and may also make it more difficult to use available memory space efficiently. Some interesting new concepts in memory organization have been suggested for image data and should be further researched.

Computer Systems: Software

Several of the potentially fruitful areas for hardware research suggest corresponding software needs. For parallel processing to become widely adopted, it will be necessary to improve on existing high-level languages for parallel programming. These languages also need to have constructs for specifying spatial relations and operations in order to facilitate the implementation of map algebras.

Although digital device research is steadily increasing the density with which image data can be achieved, it is unlikely that the need for ever greater storage capacity will be satisfied by this route alone. Research continues to be needed into methods for image data compression. The considerable redundancy that often exists among diverse image of the same scene remains to be exploited for this purpose.

Finally, since the human data analyst is likely to remain a significant component of the processing ensemble for the foreseeable future, efforts to make the analyst's role more effective will continue to pay dividends. Image data bases should be designed to make transparent the physical interface among the various forms of image data. The analyst should be able to browse efficiently through a large data base in search of data with given spatial, temporal or other attributes. And he should be able to specify the operations to be performed on the image data in an efficient and natural manner.

SUMMARY OF DATA PROCESSING RELATED RECOMMENDATIONS

Realizing that only finite resources are available to pursue data processing research for remote sensing, how should we prioritize the use of these resources? Insufficient time was available for the workshop attendees to address this question explicitly, although it clearly was on the minds of all. A few thoughts on this subject, based on general impressions from the proceedings, will be presented.

To arrive at any sort of prioritization, one must again adopt an orientation based on "use drivers" or "possibility drivers." Consistent with our earlier discussion, we recommend the latter, emphasizing the possibility of potentially high-return breakthroughs which could substantially increase the overall utility of remote sensing and geobased information systems.

We thus summarize by listing as specific recommendations only what appeared to be the highest priority research topics of all those discussed above:

RECOMMENDED PRIORITY RESEARCH TOPICS

1. SPATIAL/CONTEXTUAL REASONING
    Tools for spatial computing
    Artificial intelligence/expert systems

2. SCENE MODELING/UNDERSTANDING
    "Macroscopic" world models
    "Microscopic" physical models

3. HIGH DIMENSIONAL DATA METHODS
    Tools for high dimensional data design, analysis, processing, and storage.

The need for "spatial reasoning" methods may have been the most frequently mentioned subject in the workshop. This term refers to information extraction processes significantly more powerful than the multispectral pixel-oriented processes which have been emphasized in the past. Actually, a better term than "spatial reasoning" is "contextual reasoning," since what is actually referred to is reasoning based on any or all information available, local or global, about a given scene location. Such processes would incorporate relatively high-level intelligence in the decision-making operations. Given the wealth of data now available and the types of information sought from geobased information systems, research in this class of information extraction processes may well be expected to produce significant breakthroughs.

Success in contextual reasoning research may depend significantly on successful research in scene modeling and understanding. Macroscopic world models are required to represent known information about the real world so that this prior knowledge can be utilized in the information extraction process. The need for microscopic physical models is two-fold: to provide insights needed to improve the world models, and to permit solution of the "invertibility problem" when the application requires recovery of real scene parameters from the measured data.

Based upon the advances made in sensor technology in recent years, the construction of arrays capable of large numbers of spectral bands is a definite likelihood. While current analysis techniques are logically extendable to large numbers of features, in fact they cannot be used very well in that case. Further, the increased availability of multitemporal data via registration, of radar data, and of geo-databases containing large numbers of different types of georeferenced data suggest that techniques are needed for analyzing multivariant data of high dimensionality. Though new high dimensional optical sensors will deliver data whose various components are homogeneous in the sense that the same statistical models may be suitable for all dimensions, the georeferenced databases, which are heterogeneous in the sense, will likely require wholly different techniques. Beyond analysis, the emergence of technology which can produce high dimensionality optical sensors raises anew the question of data design, i.e. how should such sensors be designed for maximum information yield. Other types of processing and storage technology will be needed as well for this data.

Whereas these are three strong candidates for highest priority in a technical sense, there are two additional high-priority matters which must be raised to do justice to the workshop deliberations. These are Education and Cross-Disciplinary Communication. The computer-based tools of modern remote sensing and geobased information systems must be communicated effectively to and within the user disciplines so that research results can be "fire-tested" in real applications and appropriate feedback received by the research community. This is particularly challenging because of the highly multidisciplinary nature of the subject matter. Indeed, cross-disciplinary communication is essential not only to facilitate education but also because it tends to amplify research progress. Funding agencies interested in remote sensing and geobased information systems will foster progress in these areas by encouraging multidisciplinary team research and sponsoring multidisciplinary symposia and workshops.

V. SUMMARY

In this National Science Foundation Workshop on the Engineering Aspects of Remote Sensing, a group of 24 respected researchers gathered for 2 1/2 days to consider the current status and most useful future directions for the field, and in particular, the Engineering aspects of it. In doing so, the perspective was clearly not that the field is either exclusively a science or an application, or even that it dichotomizes into the two. Rather it was viewed as a continum extending through both.

At this time, the field finds itself, in a sense, at the end of a cycle and the beginning of a new one. It has, in these past years, past consecutively through phases of concentration on first achieving new capabilities to gather Earth observational data, next, understanding what the data tell us, and finally, applying this new knowledge to practical use. It would clearly be more effective in the national interest to be doing a balanced amount of these three continually; however, it is clear that a new thrust at the more strongly Engineering portion of the research spectrum is now needed, thus the timeliness of this workshop.

During the recent years when the concentration has been on applying, substantial amounts of new knowledge have accumulated in related Engineering fields and await the research needed to mold and extend these ideas and abilities to the needs of the Earth Observational field. This accumulated knowledge comes in the developments in solid state electronics and physics, in antennas and other microwave devices, and in a variety of information processing systems developments from new signal processing concepts to processing hardware abilities to artificial intelligence, display technology and human factors considerations.

Out of the discussions and conclusions of the Workshop several major specific opportunities for future development can be identified as possible or probable. These include:

OPTICAL

- Substantial increase in spectral detail
- Feasible high resolution sensors at geostationary orbit
- Variable spectral width bands
- Off nadir pointing
- Polarization sensors

MICROWAVE

- Higher power levels available
- Forward scatter radar (via dual platforms)
- Significantly advanced antennas

- Data rate mitigation via on-board processing

These developments in the sensors area, together with newly arising information processing developments provide for a substantial number of data processing areas which appear in need of increased fundamental understanding. Among these are:

DATA PROCESSING

- Techniques for analyzing high dimensionality data
- Advances in feature design techniques
- Processing of combined optical/microwave data
- Advanced temporal sampling analysis techniques
- Analysis techniques for slant view data
- Calibration procedures, and better understanding of the interaction between atmospheric and ground effects on sensed radiation
- Use of global and syntactic spatial information in analysis

There are many more areas which were discussed and appear to have promise for development. Examples are advanced statistical decision theory techniques, change detection approaches, data base technology, display technology and the human interface, use of parallelism in processors, better understanding of the noise-to-signal relationship, data compression techniques, modeling of micro and macro processes in nature, and others. We intentional are not exhaustive in these listings, attempting only to provide illustrative or representative area, as it is most essential, especially at this time, to allow for and to expect creativity on the part of the scientific community in devising new approaches for study.

The essence of remote sensing is that the synoptic view provides the opportunity to gather data which cannot be gathered in any other way. Advances in space capability and sensor technology provide an ever growing opportunity to do so. Skeptics frequently predict that "we will bury ourselves in data". The growing technology of information processing, when mated with a sound research program to increase our fundamental understanding will provide the ability for the users of this technology to make the right choices so that rather than simply being buried in data, the users can have a rich and effective source of information.

APPENDIX A: Proposal for Workshop

INTRODUCTION

Numerically oriented remote sensing technology had its beginnings in the mid 1960's. The primary factors involved in the initiation and development of the technology were the initiation of fundamental studies based upon field data, the deployment of airborne multispectral scanners that operated in the visible, infrared, and microwave regions, and the application of pattern recognition theory to the digital computer analysis of the multispectral data produced by the airborne scanners. Progress in the early development of the technology was rapid as new analysis techniques were applied and instrumentation improved. A "leap frog" phenomenon occurred in which significant development in either computational power or technique seemed to put pressure on the development of superior instrumentation. When the instrumentation characteristics improved this in turn encouraged more rapid development of the analytical techniques.

However, the launch of the first Landsat MSS in 1972 ushered in a new era of remote sensing technology development. There was a strong emphasis on the application of technology to a variety of problems of the earth's resources. The applications emphasis was so strong that there was a general slowing in the development of the basics of remote sensing technology. Even though a new instrument, the Thematic Mapper, has been recently launched, there seems to be a general feeling in the remote sensing community that the technology is on a plateau as far as the development of improved sensors or analytical techniques is concerned.

To be sure, nagging problems of applications and operations persist, such as acquisition of timely data over important targets, timely distribution of the data to interested users, data processing costs, overall satellite system costs, etc. However, besides continuing to work on these problems directly, as has been the primary thrust of the last ten years, there is reason to believe that returning to the more fundamental approach, which produced the rapid development of the 1960's, could again produce the ingredients for rapid progress and could provide a fresh approach as a basis for further advancement of applications and operations capability.

PROPOSED WORKSHOP

It is proposed that a workshop of the most qualified scientists and engineers be convened to examine the validity of this premise and to define the directions which such a research program must take in order to provide maximum benefit in its scientific and technological return. The workshop would be organized around a three day work period with a maximum of 40 participants. In order to stimulate thought and discussion there would be defined three topical discussions areas as follows:

1. Information Potential in Remote Sensing
2. Sensor and Measurement Technology
3. Processing Methods and Systems

A paragraph more completely describing each of these is contained on the attached pages.

Each topical discussion would be approximately one half day in length. It would be initiated by a keynote statement of about 30 minutes, in which a speaker and discussion leader especially selected for his/her qualifications in the topical area would discuss the topic. As well as serving to keynote and focus the half day discussion, the leader would provide some initial "straw man" ideas as to the conclusions about the area. After a discussion period of perhaps 30 minutes for the group as a whole, the group would be divided into four individual discussion groups. Each would individually discuss the topic and attempt to come to tentative conclusions.

After this process has been repeated for all three topical areas, using approximately the first day and a half, the group would meet as a whole to hear and discuss reports from the four individual groups and to draft and approve the final report of the meeting.

The rationale for structuring the meeting in this way is as follows. The keynote and brief general discussion is intended to define the topical area well in the minds of the participants, clearly indicating the center point of the topic rather than bounding it. The early use of small discussion groups should aid in drawing out ideas from all the participants and should help to avoid domination of the meeting by a few. The concluding general sessions would then facilitate achieving and documenting a consensus.

The topical areas selected are intended to provide the desired focus on the engineering aspects of remote sensing, but to do so from an integrated systems viewpoint. The first area is intended to provide this integrated systems perspective; it is then followed by discussions which can adequately give consideration to the individual systems elements of the sensor and processing systems.

The budget is planned to assure attendance by key people of the field and to provide adequate support before, during, and after the meeting. A list of possible invitees is included to illustrate the type of mix most desirable. The list includes persons specializing in optical and microwave sensor systems, data base systems, and all phases of processing algorithms and hardware. Although it contains a majority from the academic sector, some participants from government and especially from industry are included as well.

The end purpose of the workshop would be to gather together the best ideas possible on needed research of a basic nature on the engineering aspects of remote sensing, and to stimulate the thinking of well qualified scientists and engineers on this subject.

Topical Area #1. INFORMATION POTENTIAL IN REMOTE SENSING

It has been customary, when pondering the possibility of researching new technology for remote sensing, to start implicitly with the assumption that the information potential is so large that it need not be assessed quantitatively. New sensor designs are therefore based on purely subjective conclusions; for example, that more spatial resolution or more spectral bands will always deliver more information to the processing system and that the chief factors which serve to limit the sensor design are the engineering difficulties in constructing and operating a sensor system.

However, much has been learned in the past number of years about what aspects of spectral, spatial, and temporal variations of land area measurable at extraterrestrial altitudes are significant in their information potential. Indeed the science has matured to the point that it is now appropriate to study the inherent information potential of earth oriented space sensors and the means by which this information potential can be quantified in a more objective fashion and used for devising the specifications of future sensor and processing systems.

This topical area is then broad in its scope, not focusing specifically upon either the sensor or the information extraction process, but attempting to stimulate thinking into the question of just what features of the Earth's surface are information-bearing, and what are the bounds on the amount and type of information which could be extracted.

Topical Area #2. SENSOR AND MEASUREMENT TECHNOLOGY

Advances in remote sensing technology seemed to have come about in a steadily growing fashion as breakthroughs occurred in the various components of the technology. First manual analysis of air photographs was used. This suggested the need for scanners to make available imagery from infrared regions. But scanners allowed the data to take on a more quantitative character, and the development of the airborne single aperture multispectral scanner allowed the study of digital computers to analyze the data, leading the field toward the study of sophisticated information extraction techniques. Spaceborne scanners were then developed along with multiterminal time share computer systems and pattern recognition methodologies were applied in the data analysis.

Now there seems to have been a general maturing of the basic components of the technology. If another quantum jump of growth is to occur it seems as though it will be based on a breakthrough in basic sensor technology. We would anticipate that this portion of the workshop would address the fundamental techniques of sensing radiometric imagery, both optical and microwave, what changes are taking place in these fundamental technologies which might influence the ways in which remote sensing sensor systems are designed, and the possible data parameters which might be materially improved as a result.

Topical Area #3. PROCESSING METHODS AND SYSTEMS

As the sources of information relevant to remote sensing become more numerous and varied in type, format, and resolution, new and more powerful methods are required to utilize these information sources effectively. Areas in which research may prove fruitful include (a) multivariate statistical models and classifiers, (b) clustering techniques (unsupervised classification), (c) syntactic analyzers, (d) expert systems and other man/machine/data interface methods, (e) dimensionality reduction techniques, (f) data structures for multitype, multiresolution data, (g) specialized computer architectures, (h) query techniques for spatial data bases, (i) analysis techniques for spatial data bases. (j) generalized rectification/normalization methods.

APPENDIX B: List of Attendees

Joseph K. Berry, Associate Prof. and Assoc. Dean
Yale University
School of Forestry & Environ. Studies
205 Prospect Street
New Haven, CT 06511

Education: B.S. in Forestry, Univ. of Calif. - Berkeley, 1969 M.B.A. in Business Management, Colorado State Univ., 1973 Ph.D. with emphasis in Remote Sensing, Colorado State University, 1976.

Applicable Experience: He is involved in research and graduate level instruction in computer-assisted analysis of geographic information. Earlier research was on spectral signature extension in natural scenes. His current basic research involves the development of a generalized mathematical structure for analyzing mapped data. His applied research deals with the spatial characterization of natural resources in physical, economic and social terms.

Fred Billingsley
MS 168-514 Jet Propulsion Lab
4800 Oak Grove Drive
Pasadena, CA 91109

Education: B.Ch.E., Rensselaer Polytechnic Inst.; B.E.E., Rensselaer Polytechnic Inst.; M.E.E., Rensselaer Polytechnic Inst.

Applicable Experience: 20 years in image analysis. Built the JPL Image Processing Lab. Landsat investigator on several investigations, beginning with ERTS-1. Participant in numerous Landsat & other NASA earth-observations workshops.

Keith Carver, Head
Dept. of Elec. & Comp. Eng.
University of Massachusetts
Amherst, MA 01003

Education: B.S. Electrical Eng., Univ. Kentucky, 1962; M.S. Electrical Eng., Ohio State Univ., 1963; Ph.D.Electrical Eng., Ohio State Univ., 1967;

Applicable Experience: Program Manager for Microwave Remote Sensing (NASA HQ, 1981-82). Chair, SIR-B, SIR-C Science Working Groups. Various other NASA microwave r.s. committees. Papers, books.

Herbert Freeman, Professor of Computer Engineering
Director of Image Processing Laboratory
Rensselaer Polytechnic Institute
Troy, NY 12181

Education: B.S.E.E., in electrical engineering; M.S.E.E., in electrical engineering; Dr. Eng. Sc., in electrical engineering

Applicable Experience: computer image processing/pattern recognition/computer graphics

Morris Goldberg
Dept. of Electrical Engineering
University of Ottawa
Ottawa K1N 6N5
Ontario, CANADA

Education: B.Sc. (Math); Ph.D. (Electrical Engineering)

Applicable Experience: International Association on Pattern Recognition Consultant, Canada Centre for Remote Sensing, Canadian Department of Environment. Interests are Pattern Recognition and Image Processing for Remote Sensing.

David G. Goodenough, Head
Methodology Section
Senior Research Scientist
Canada Centre for Remote Sensing
2464 Sheffield Road
Ottawa, Ontario K1A 0Y7
Canada

Education: B.Sc. (Honors Physics), U.B.C., 1964; M.Sc. (Radio Astronomy), U. of Toronto, 1967; Ph.D. (Optical Astronomy), U. of Toronto, 1969

Applicable Experience: Research in remote sensing information extraction methods over past 11 years with aircraft, satellite, and ground based data. Published more than 50 papers in areas of interest in workshop session.

Robert M. Haralick
Dept. of Electrical Engineering
Virginia Polytechnic Institute State University
Blacksburg, VA 24061

Education: B.A. Math, Kansas University, 1964; B.S. EE, Kansas University, 1966; M.S. EE, Kansas University, 1967; Ph.D. EE, Kansas University, 1969

Applicable Experience: Computer Vision, Image Processing, Artificial Intelligence, Pattern Recognition.

Warren A. Hovis
NOAA/NESDIS E/RA2
Washington, D.C. 20233

Education: B.A. Physics, John Hopkins University, 1953 Ph.D. Physics, John Hopkins University, 1961

Applicable Experience: Aircraft remote sensing with spectrometers and imagers in the visible, near IR and thermal IR. Spacecraft experience as principal investigator on Nimbus 4, 5 and 7. Sensor Scientist Landsat (ERTS-1) Radiometric calibration of space and aircraft sensors in the optical region.

David A. Landgrebe, Professor of EE
School of Electrical Engineering
Purdue University
W. Lafayette, IN 47907

Education: BSEE 1956 Purdue University; MSEE 1958 Purdue University; Ph.D. 1962 Purdue University

Applicable Experience: Teaching and Research in Signal Representation and Information Processing. Director of LARS 1969-81. P.I. of ERTS-I, Landsat, Skylab and a number of other remote sensing research projects.

George H. Ludwig
880 Crescent Drive
Boulder, CO 80303

Education: B.A. (Physics) Univ. of Iowa; M.S. (Physics) Univ. of Iowa; Ph.D. (EE) Univ. of Iowa

Applicable Experience: Space research - Space radiation (Van Allen belts) 1956-65. Space research data processing 1965-72. NOAA operational sat. systems - satellites, opns, data proc. 1972-80. Headed ERL 1981-83. Data mgmt study for NASA June 83-Jan 84. Member, NAS-CODMAC.

Robert E. McIntosh, Professor
University of Massachusetts
Microwave Remote Sensing Laboratory
Amherst, MA 01003

Education: B.S.E.E. Worcester Polytechnic Institute S.M. (Applied Physics) Harvard University Ph.D. (EE) University of Iowa

Applicable Experience: Co-directs the Microwave Remote Sensing Laboratory (MIRSL). This lab is involved with the development of advanced microwave sensors for remote sensing of oceans, cryosphere and land surfaces. His primary research is in the area of microwave radar scattering from ocean surfaces with applications in the areas of wind speed, and ocean surface current measurements. Other interests are passive remote sensing of tropical storms and the marginal ice zone with radiometers.

Edward M. Mikhail
School of Civil Engineering
Purdue University
West Lafayette, IN 47907

Education: B.S. Civil Engineering; M.S. Photogrammetry and Geodesy, Cornell University; Ph.D. Photogrammetry and Geodesy, Cornell University

Applicable Experience: In charge of graduate instruction and research at Purdue for photogrammetry, data adjustment, and metric aspects of digital images, digital image processing, and remote sensing.

George Nagy
Computer Sciences Dept.
University of Nebraska
Ferguson Hall
Lincoln, NE 68502

Education: B. Eng. Physics, McGill, 1959; M. Eng. EE, McGill, 1960; Ph.D. EE, Cornell, 1962

Applicable Experience: Active in pattern recognition, image processing, data structures for geographic information systems, quantitative studies of man-machine interface. Has participated in various N.A.S., N.A.S.A. and A.A.A.S studies on remote sensing.

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Texas A & M University
College Station, TX 77843

Education: B.S.E.E.; M.S.E.E.; Ph.D.

Applicable Experience: Modeling of electromagnetic phenomenon (primarily microwave spectrum). Sensor system design and development - active and passive microwave and lider and visible veer IR spectroradiometer. Considerable work developing methods of using microwave sensors for soil moisture measurement, hychologic parameters and methods classification.

Virginia T. Norwood, Senior Scientist
Electro Optical Systems Group
Hughes Aircraft Company

Education: Bachelor of Science, MIT;

Applicable Experience: Conducted initial studies and system engineering through design phase for MSS and Thematic Mapper. Background includes antennas, microwave circuits, SAR, communications and visible/IR sensors.

Leroy Silva, Professor of EE and Ball Professor of Engineering
Business & Industrial Development Center
Engineering Administration Bldg.
Purdue University
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Education: B.S. 1952, Purdue University; M.S. 1954, MIT; Ph.D. 1965, Purdue University

Applicable Experience: Program Leader for Measurements at Laboratory for Applications of Remote Sensing at Purdue, 1970-present.

David S. Simonett, Dean, Graduate Division
Professor of Geography
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Sanata Barbara, CA 93106

Education: B.S, M.S., Ph.D. Geography, University of Sydney, Sydney, Australia.

Applicable Experience: Associate Director, Remote Sensing Laboratory, Univ. Kansas, 1965-70. Head, Dept. of Geography, University of Sydney, Australia, 1970-72. Director, Land Use and Agricultural Applications Division, Earth Satellite Contention, Washington, D.C., 1972-19__. Professor and chair, Geography Dept., Univ. of Calif., Santa Barbara, 1975-19__.

Philip N. Slater, Chairman, Committee for Remote Sensing
Professor, Optical Sciences
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Education: B.Sc. (Physics), Ph.D. (Applied Optics) Imperial College, University of London.

Applicable Experience: Interests are in absolute radiometric calibration of remote sensing systems, atmospheric characterization & correction, sensor design. Author of "Remote Sensing: Optics & Optical Systems". Presently investigator on the in-flight absolute radiometric calibration of the Thematic Mapper.

James A. Smith, Professor of Remote Sensing
Dept. of Forest and Wood Sciences
Colorado State University
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Education: B.S., M.S. Mathematics, University of Michigan; Ph.D., Physics, University of Michigan

Applicable Experience: Remote Sensing with specialization in electromagnetic terrain modeling. Teaching responsibilities include survey courses in remote sensing applications to natural resources, geographic information analysis, and image processing. Technical Editor, Optical and Infrared Area, IEEE Geosc. & Remote Sensing.

Philip H. Swain, Associate Professor of EE
School of Electrical Engineering
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Education: B.S.E.E., Electrical Engineering, Lehigh Univ., 1963; M.S.E.E., Electrical Engineering, Purdue Univ., 1964; Ph.D., Electrical Engineering, Purdue University, 1970

Applicable Experience: Pattern Recognition, Machine Intelligence, Image Understanding, Remote Sensing, and Parallel Computing Methods and Systems.

James C. Tilton
Science Applications Research
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Education: B.A. (Electrical Engineering, Environmental Science & Engineering & Anthropology, Rice University), M.E.E., Rice University, M.S. (Optical Sciences)

University of Arizona, Ph.D. (Electrical Engineering) Purdue University.

Applicable Experience: Pattern Recognition, Image Analysis, Artificial Intelligence techniques applied to Remote Sensing. Main work has been in the area of developing computer algorithms for analyzing remotely sensed data, particularly algorithms that utilize spatial information in data at 10-30 meter resolution (and to a lesser degree at 80 meters).

Stephen G. Ungar,
Earth Observation Division
NASA Goddard Space Flight Center

Education: B.S. Physics; M.A. Physics; Ph.D. Astrophysics

Applicable Experience: Former director Earth Resource Program at NASA Goddard Institute for Space Studies. Specialized in simulation studies leading to observing system design/Interpretive Technique development.

Vern Vanderbilt
Laboratory for Applications of Remote Sensing
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Education: B.S. EE, M.S. EE, Ph.D. in EE

Applicable Experience: Performing research in area of light scattering properties of leaves and plant canopies to better understand the information contained in their reflectance spectra.

John B. Wellman, Manager of the Infrared and Analytical Instruments
Systems Section.
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Education: B.S., M.S. Physics, Purdue University M.E. (Master of Engineering), UCLA

Applicable Experience: Manager of the Infrared and Analytical Instruments Systems Section, Observational Systems Division, JPL. Until August 1983, was Instrument Manager in the JPL Imaging Spectrometer Program and the Shuttle Imaging Spectrometer Experiment (proposed).

G. J. Zissis, Professor
ECE Dept.
College of Engineering
University of Michigan

Education: B.S., Physics, Purdue University, 1946; M.S., Physics, Purdue University, 1950; Ph.D. Physics, Purdue University, 1954

Applicable Experience: Univ. of Michigan, Willow Run Laboratories, 1955-1973. Member and chairman of NAS/NRC CORSPERS; Editor-in-chief of Journal of Remote Sensing (BLSEV Press).

APPENDIX C: Workshop Schedule
February 28, 29, March 1, 1984

Tuesday

8:00am Registration - Stewart Center

8:30am Organization & Opening Remarks

9:00am Work Session on Potential Information Content of Remote Sensing Observations
Speaker: Fred Billingsley 30 minutes
Plenary Discussion 30 minutes
(Subdivision into three working groups)
Discussion in Working Groups 2 hours

12:00 N Lunch

1:00pm Work Session on Sensor Systems
Speaker: Warren Hovis 30 minutes
Plenary Discussion 30 minutes
Speaker: Keith Carver 30 minutes
Plenary Discussion 30 minutes
Discussion in Working Groups 2 hours

5:00pm Adjourn

6:30pm Refreshments and Dinner - SHERATON INN OF W. LAF.
3001 Northwestern Ave.

Wednesday

8:30am Work Session on Data Processing
Speaker: Robert Haralick 30 minutes
Plenary Discussion 30 minutes
Speaker: Herbert Freeman 30 minutes
Plenary Discussion 30 minutes
Discussion in Working Groups 2 hours

12:00 N Lunch

1:00pm	Working Groups work session	3 hours
4:00pm	Plenary Preliminary Report Session	1 hour

Thursday

8:30am	Report Drafting in Working Groups	90 minutes
10:30am	Final Report in Plenary Session	90 minutes
12:00 N	Adjourn	

For NSF Workshop on Remote Sensing
Purdue University February 1984

APPENDIX D: Billingsley Paper

INFORMATION POTENTIAL OF REMOTE SENSING

Fred C. Billingsley
Jet Propulsion Laboratory
Pasadena, California 91109

INTRODUCTION

I can do no better in starting this discussion than to quote Dave Landgrebe's proposal for this Technical Area:

> It has been customary, when pondering the possibility of researching new technology for remote sensing to start implicitly with the assumption that the information potential is so large that it need not be assessed quantitatively. New sensor designs are therefore based on purley subjective conclusions. For example, more spatial resolution or more spectral bands will always deliver more information to the processing system and that the chief factors which serve to limit the sensor design are the engineering difficulties in constructing and operating a sensor system.
>
> However, much has been learned in the past number of years about what aspects of spectral, spatial, and temporal variations of land areas measurable at extraterrestrial altitudes are significant in their information potential. Indeed the science has matured to the point that it is now appropriate to study the inherent information potential of earth oriented space sensors and the means by which this information potential can be quantified in a more objective fashion and used for devising the specifications of future sensor and processing systems.
>
> This topical area is, then, broad in its scope, not focusing specifically upon either the sensor or the information extraction process, but attempting to stimulate thinking into the question of just what features of the earth's surface are information-bearing, and what are the bounds on the amount and type of information which could be extracted.

In line with this approach, we will try to identify ways of thinking about "perfect interpretation" and the possible loss functions which prevent perfect interpretation. We will not be restricted by any reasonable potential sensing technique or parameters - we will include the questions of adjusting conventional sensing techniques, and accept propositions for new sensing techniques.

Suppose you could "be there", and could look but not touch. What would you look for? In what directions? With what sensors? Why? Under what conditions? How well? With what accuracy? What phenomena are appropriate to investigate? Would you desire to derive phenomena requiring touching? How could you substitute seeing for touching?

The interpretation domain includes discrimination of materials, identification of materials, and the understanding of the underlying processes and relationships. It is recognized that it is difficult to separate the information potential from modeling and potential upgrades in information extraction techniques [Landgrebe 1983]. Indeed, the possibility of new models may open the way for the suggestion and utilization of new phenomena to be sensed.

One point must not be overlooked by the remote sensing protagonists: for many tasks, although remote sensing may be useful, it may not be needed or desired [Billingsley, 1979; Philipson, 1980]. Thus even though potentials may be shown by the protagonists, they may not be adopted by the user community.

Over the past decade, the primary emphasis has been on the direct useage of the data gathered, and the approach has been "more is better", based on the assumption that answers to questions such as listed call for higher everything than currently available. Various modifying effects, such as that of the atmosphere, have been grudgingly recognized. In general, the requisite data for accomodating these effects have not been available. Optimization of the information potential requires consideration of the effects of several interrelationships on the possibility and accuracy of analysis, such as:

- Between sensor parameters
- Between sensor and interference parameters
- Between sensor and scene parameters
- Between platform parameters and sensor parameters
- Between any of these and the analysis techniques and results

But consideration of interrelationships is a system question. Thus we are led immediately to consider the system problem as well as problems involving the individual parameters. And even this concept has two levels: system optimization for a given discipline (such as the Coastal Zone Color Scanner), and optimization across a number of disciplines.

DATA VS. INFORMATION

At least two factors force consideration of potential tradeoffs between sensor parameters: a not-unlimited data rate and the related data volume problem, and the necessity of trading off parameters due to sensor limitations. At least six parameters may be up for grabs: spatial resolution, spectral number of bands, signal-to-noise and number of bits of quantization in the sensor, data coding techniques, swath width, and revisit interval.

The tradeoff must be considered in relation to the ability of the user to turn cold, impersonal data into a live, personal decision or piece of information. Therein, of course, lies the sleeper: the data system designer requires data parameters, and is dependent on the user to convert his information needs to these data parameters. This conversion will be done with more or less accuracy, beginning a chain of inaccuracies which in the end hamper the user from obtaining the information desired.

We will first consider a generic problem, optimization of an information system, as shown in Figure 1 [Billingsley, 1981]. The forward model is required to convert units of information to units of required data, and answers the question "What set of measurements will best carry (allow the best derivation of) the information?" This box provides the measurement "requirements" to the system, which responds with a set of real measurements which will hopefully be somewhat near to the requested set. It is with this set that the user attempts to derive his information, using the information model.

Design and evaluation of the system takes place at two levels, as shown in Figure 2. The evaluation, and therefore the design, of the total information system is the joint responsibility of the user and the data system designer, as model boxes under the cognizance of each are involved. The data system designer cannot be held for the inadequacies or uncertainties in either the forward or information models, although he is deeply interested in the validity of each.

Care must be taken in designing the models and the systems which they represent. Figure 3 applies to both models and systems. At the low end of complexity, the system may provide only a nominal solution to the information problem A , and so the potential errors due to the design may be quite large. But at least, B , the data can be obtained. At the other extreme, a complex model D can produce the required results quite accurately, if only the data required for the solution could be obtained C . If it can be identified, the saddle point E is the optimum complexity to design to. In the case of image registration, for example, the saddle point may be found to be at 0.5-1.5 pixel accuracy level, fairly broad, with moderate gains obtained with very complex processing if the requisite data (e.g., world wide GCPs or the GPS operational)are obtainable. At the low end, simple processing may produce only moderate registration accuracy and so decrease useability.

We will consider Figure 4 as a design model for information system optimization. The desire is to minimize the sum of the weighted losses in interpretability due to all causes. This is thus seen as a linear programming problem. Parameters available for adjustment include the sensor basic parameters (resolution, spectral, quantization, revisit), anticipated interference factors (such as orbit uncertainties or radiometric uncertainties) and the ability to measure these, the calibration forward model (how well do we plan to remove the errors?), availability of calibration references, the efficacy of rectifications, and the user's forward and information models (the user may do things differently than desired if the anticipated real data will be too divergent from the data desired or if it will be accompanied by too large errors). The linear programming requires a knowledge of the rate of loss in information with deviation in parameters, both singly and in combination.

Some sensitivity studies have been undertaken [for example, Ramapriyan et al, 1981; Buis et al,1983]. However, in general most such studies deal with perterbations among data sets already obtained , and the bogie parameters, sensitivity coefficients, and cross-sensitivity coefficients required to do a quantitative system optimization will generally not be available. Nevertheless, these are implicitly defined in the designer's mind, with or without affirmation by the users. Much fundamental research needs to be done to define the forward and information models and to obtain the sensitivity factors, to allow these to be used in a quantitative total information system design.

PARAMETER RESEARCH ISSUES

Landgrebe et al [1977] studied some of the tradeoffs between parameters for a limited range of parameter values. This is a complex problem because of the interrelationships between many of the parameters. They found that, in general, decreasing instantaneous field of view (IFOV) decreased classification accuracy and increased mensuration accuracy, and that within the limits of the parameter values studied, noise and spectral band selections were not definitive.

Holmes [1981] has outlined a number of research issues in the report on Electromagnetic Measurements and Signal Handling to the NASA Fundamental Research program. Of particular interest to the present discussion is the recognition of the problem in obtaining sufficient data to allow a complete system design. Specifically called for is the gathering of data with parameters appreciably exceeding those rationally expected to be utilized in an eventual mission. Only by having all parameters which are candidates for tradeoffs simultaneously available can the "more is better" question be optimized. This is at some variance with the normal practice of trading off between parameters which have already been approximately fixed.

Now that the system design is under control (!), let us turn our attention to some of the individual parameters.

SOME THOUGHTS ON MODELS

Judicious use of models may expand the "information" synthesized from the data. A potential problem with models is that the analysts tend to believe they are the real world, rather than a construct which has been calibrated with the data. Models tend to be generated and applied at the edges of interpretability, and so may be subject to extrapolation type errors. Maxim and Harrington [1982] mention this in their discussion of scale-up estimators: " It is important to emphasize that, if an aerial survey is analyzed with such models without the guidance of a ground truth sample, then the results must be examined very carefully, ... " (emphasis theirs).

SPATIAL RESOLUTION

Responses to the Applications Survey Groups survey [Billingsley et al, 1976] on resolution, following the Landsat MSS experience, indicated that "80 meter resolution is about right". Subsequent surveys indicate that "30 meters looks good", and that there might be some use for 15 meter resolution. There seems to be no real limit to user expectations except data handling. Unfortunately, there also seems to be no firm rationale for any particular
resolution.

An exception is the study by Welch [Welch, 1982] which indicated that spatial resolution of under 5 meters is required to make cartographic maps at 1:24000 or larger (note that even this assumes a certain end product).

In another study [Welch and Petrie, 1982] he indicates the degree of completeness which may be attained with various instantaneous field of views (IFOV) (Figure 5). Again, the indication is toward a 5 meter pixel size, which is about the resolution to be attained by the Large Format Camera.

Other studies on resolution [NASA MISWG and others], call for resolutions of 1-2 meters for urban studies, increasing classification accuracy with large pixels for forest studies [Latty and Hoffer, 1981], up to "very large" pixels for water studies. Agriculture studies generally call for small pixels to avoid the mixed pixel problem, which comes about in small fields due to adjacency effects. Given the desire to measure very small fields, there seems to be no rational lower limit to required pixel size, until this small size causes some parameter to increase sufficiently to decrease classification accuracy.

Nyquist sampling is required if any interpolations, such as for geometric corrections, are to be employed. This requires that instantaneous fields of view be overlapped by 50% or more. But it is well known that this criterion is not met in the usual sensors, and that minimal deleterious effects have resulted (as far as we know, but see Friedman, 1981). How might this be?

1) Sensor internal: Integrating detectors reduce the along scan line resolution, so that the IFOV is not just the aperture footprint. The effective field of view typically is about 50% greater than the detector geometric footprint [ASP Manual of Remote Sensing].

2) Sensor to scene: Scenes do not have amplitudes of the high spatial frequencies equal to that of the low. This comes about from the 1/f spatial frequency amplitude content of even sharp edges, coupled withthe random distribution of such edges. Only in the case of an expanse of regular features, such as shown in Figure 6, will high spatial frequencies occur with appreciable amplitudes. Thus the aliasing power generated is usually low.

3) Sensor to analysis: Many analyses do not use interpolations. Other analyses are restricted to scene object sizes of several pixels or larger. This, of course, is the multispectral small-field problem with pixels near the field boundaries. "Scene noise" is averaged out when using larger pixels or when averaging pixels in nominally uniform multi-pixel scene areas. This is advantageous for multispectral classification, but in some analyses the scene noise is considered as texture, and is a diagnostic.

Another area in which multi-pixel objects are required is the identification of objects by their shape, which requires 10 - 15 pixels per object for good recognition [Scott and Hollanda, 1970] (Figure 7).

A third area of spatial resolution interaction with the scene is in the sensing of objects about the size of the sensing cell. This might be termed "Sub-Nyquist Interpretation". Imaging theory puts this in a never-never land - the object is small enough to cause pixel-pixel texture, but too small to recognize. But this is continually attempted. Wehde found that "When a map unit is of a size approximately equal to that of the cells being used to represent the map, a wide variation in mapping error is possible depending upon the position of the grid cells with respect to the map unit" (although) "the mapping error averaged out over all possible grid positions is well behaved ..." [Wehde, 1982] (Figure 8). This is precisely the effect to be expected when the sampling rate is one-half the Nyquist value (double the allowable spacing) and dominant material coding is used. Unfortunately, at whatever pixel size is chosen, some one will attempt analysis at the limit of resolution.

This is part of the general subject of feature scaling, which has been studied in the context of map generalization and completeness [Welch and Petrie, 1982]. Welch et al [1981] have reported on the activities of the ISP Image Quality Working Group in investigating some interrelationships between spatial and radiometric resolutions.

A task for system design will be to evaluate the information-extraction loss functions for the various analyses as a function of sensor resolution. A second necessary system task is to evaluate at what resolution the benefits become asymptotically saturated especially in view of the expense involved in achieving the higher resolution

SPECTRAL BANDS

A set of different approaches to sampling have been taken for spectral sampling. At least four approaches are possible: 1) Broad band sampling 2) Narrow band sampling at spectral feature points 3) Weighted band combinations 4) Full Nyquist sampling

Broad Band Sampling This is exemplified by the MSS and TM in which the bands are determined by optical filters Characteristics are much the same as conventional color photography albeit with more bands: broad bands with non-uniform response across the bands (Figure 9) [Alford and Barker 1983] inability to sense subtle or fine spectral details or to dodge interfering spectral details The broad bands allow the separation of materials but generally defeat the desire to directly identify materials The spectacular utility has been in spite of the shortcomings. due to the sensor location on a spacecraft, digital data, and bands beyond the visible.

Narrow Bands at Selected Spectral Locations. This is exemplified by the Coastal Zone Color Scanner (CZCS). Bands have been placed at chlorophyll absorption points, hinge points, and at other spectral features characteristic of ocean sensing. The success is based on utility of these particular spectral features and ability to ignore other parts of the spectrum. The narow bands also dodge some of the atmospheric absorption features. But the CZCS approach is relatively ineffective over land, where more or other spectral features are important. The proposed Multi-linear Array (MLA) is between the broad band and narrow band catrgories: it would contain 12 or more optically-determined bands, some narrower than the TM bands, but not necessarily placed on land-based spectral features.

Spectral Band Combinations. Given the desire to reduce the number of transmitted bands or to transmit partially optimized data, the spectral bands as sensed may be combined and relatively weighted. This combination has been particularly effective in ground processing, where various combinations can be obtained from the original data sets. A possible situation might be to transmit a principal components set of bands, based on the spectral characteristics of a selected set of targets. Combination could be by optical or digital means. But the necessity to optimize for selected targets de-optimizes for everything else. This mode has not found use in satellite general purpose remote sensing.

Full Nyquist Sampling. With the availability of newer detectors, full spectral band sampling is now possible and is being implemented for research purposes [Wellman et al, 1983; Vane et al, 1983]. Ability to sense fine spectral details allows the direct identification of selected materials (Figure 10) [Hunt and Ashley, 1979; Goetz et al, 1983], measurement of atmospheric parameters, and separation of many more materials. A spectral bandwidth per sample of 10 mn with contiguous bands has been found to satisfy Nyquist, based on analyses of even finer data. The more than 200 spectral bands produced, however, place a burden on the transmitted data rate, storage capabilities, and analytical techniques.

A number of the studies of useful spectral bands have been tabulated [Vane et al, 1982]. These point to the utility of a great number of relatively narrow spectral bands in material separation and identification. However, the <u>need</u> for these identifications must be shown separately. This is part of the general task of determining the information potential of remote sensing.

A not-sufficiently-studied area is the interaction of fine spectral sampling with fine spatial sampling. The basic proposition is that fine spatial samples will tend to be of homogeneous areas, and thus will benefit from fine spectral sampling with its potentially greater material-identifying capability. The distribution of sizes of homogeneous areas of materials to be sensed has not been well studied. Basic data is now becoming available in the form of digital soils and land use maps, if the assumption can be made that the designation of a given soil type or land use type each imply homogeneous spectral response. Wehde's study of span distributions of soils types in his study area, as seen in a soils map, peaked at around 40 meters. These sources may not be indicative, however, given the normal inclination toward "cleanup" of somewhat non-homogeneous data by removal of texture within a given mapped category to avoid visual clutter, with the consequent production of larger spans .

SIGNAL TO NOISE AND QUANTIZATION

This may be approached from two points of view: 1) Given a sensor with a given noise figure, quantization noise equal to the sensor noise will produce a balanced system, with neither element predominating nor over-designed; 2) Given a defined problem, determine the required system noise figure, and then partition it among the noise sources.

The first is the normal engineering approach, assuming zero scene noise. Any anticipated scene variations may be considered as information, or may be added to the sensor noise, and the combination balanced by the quantizing noise.

The second is discussed in the Manual of Remote Sensing [ASP], Chapter 17, in the context of multispectral classification. For that problem, 6 or perhaps 7 bits is an appropriate quantization level, given practical sensors and realistic scene noise. If, however, scene variation is considered signal (that is, the texture is important), or it is desired to measure small differences in reflectivity accurately, more bits will be necessary:

> Suppose it is desired to measure the difference in reflectivity, Dr, between two areas of some low reflectivity, R. Let R=0.1 be the average of reflectivities of the two areas (almost equal to each other), and let the requirement be to measure the Dr to +-5%, 95% of the time. Atmosphere distortion to be neglected.
>
> The curves of Figure 11 apply [Billingsley, 1975]. Let +-4 DN (digital number) represent the +-5% error; the corresponding DN of R = 80, and, because r=0.1, full scale must be 800 DN. From the curves, the required beta for 95% is 0.45, requiring a noise figure of 1/(beta x full scale DN) = 1/360 = 0.0028. But 800 steps requires 10 bit quantization, which produces a noise figure of 0.00028. A sensor noise of 0.0025 is required. If the error is represented by +-2 DN, full scale must be 200, requiring 8 bits to digitize, total allowed noise is 0.0018, and a sensor noise of 0.0014 is required. Thus digitizing noise and sensor noise are traded off.

Other scenarios may, of course, be defined as appropriate. One might be, for example: How accurate must the system be, to allow measurement of the atmosphere influence accurately enough, to allow atmosphere correction, to do the above task in the presence of a real atmosphere?

The ultimate limit in sensor noise is caused by the fluctuation in the number of electrons collected for a given measurement. It is a function of the pixel size, optics f:number, dwell time, spectral bandwidth, and irradiance and atmospheric conditions. Results of the analysis of the proposed Shuttle Imaging Spectrometer Experiment (SISEX) are given in Figure 12 [Wellman et al, 1983].

The ultimate limit may be extended indefinitely with ridiculously large optics (if they can be built). A valid objective in considering information potential is to define some practical boundaries for the parameter tradeoffs, and the potential loss factors in information extraction as noise performance worsens.

SWATH WIDTH, REVISIT INTERVAL, AND COVERAGE PATTERN

If it is assumed that complete ground coverage is desired, the product of the swath width and number of swaths to cover equals the equatorial circumference of 40,000 km. Given an approximately constant orbit time of 100 minutes (for the normal low-altitude satellites), the possible revisit interval is

R = 2780 / Swath width, km (days)

If wide-field optics can be built with the required resolution, a swath width wider than the equatorial spacing will give reduced revisit time, due to overlap of the swaths, if it is accompanied by a judicious choice of swathing pattern [Billingsley, 1982]. This may be useful if BRDF and atmospheric effects are not injurious. Advantage may be taken of the differing resolution requirements vis a vis differing revisit time requirements to produce a potentially more useful sensor.

The present Landsat orbit/swath design does not allow the extraction of a complete setof NS-EW oriented rectangular images within a cycle without mosaicking. Increase of the swath width to about 210 km with the present equatorial spacing would provide sufficient overlap to allow such a set, although not on map boundaries.

The possibility of geostationary orbits has been discussed in the context of hourly or daily repeat sensing, but has generally been dismissed due to the extreme imaging requirements. Intermediate-altitude orbits with wide swaths would allow narrower optics angles and reduced BRDF effects compared to the normal lower altitude orbits, and might provide the repeat coverage desired, provided that the resolution requirements can be met.

GEOMETRIC ACCURACY AND POSITION DETERMINATION

The well known relief displacements may be considered from several perspectives. First is the displacement of individual pixels from their true positions due to their being at a different altitude than the reference plane. This is a function of the angle of wiew from the vertical. The effect is appreciable (Figure 13), and will prevent precision registration in mountaneous terrain. Inasmuch as there seems to be more fine spatial detail in mountaneous terrain, suchas smaller agricultural fields, this will hamper multi-scene registration and whatever analyses attempted. Smaller pixels will allow more pixels per field dimension, resulting in smaller misregistration losses provided that per-pixel registrtion can be held.

Related to this is the intra-image distortion and its effect on registration. The Landsat project uses a 5x5 grid of control points , when available, to generate the correction equations. Given a satellite without vibrations, this is more than necassary in flat terrain and insufficient in mountaneous terrain. Given the effort involved in establishing the control areas and in doing the correlations, a continued study is warranted toward minimizing the required number of points, in trade with the loss in utility as the accuracy of registration varies.

Chavez, on the other hand, has made use of the effect to generate artificaial stereo pairs, using surface elevation model data. The added stereo dimension increases visual appreciation considerably. Colvocoresses [1982] has proposed to use the effect for stereo mapping with the "Mapsat" satellite. Discussions on the tradeoffs of other parameters to obtain stereo have not yet been conclusive to the point of authorizing a Mapsat.

Mapping from satellites has two aspects: 1) Generation of topographic maps from stereo images obtained in a single pass, in which the attitude stability over the short period of fore-aft viewing is critical; 2) Knowlege of precision location of each pixel, in which spacecraft location and sensor attitude are critical. Given the lack of ground control over large areas, location extrapolation will be necessary until GPS and precision sensor pointing are available to the unclassified community. Estimates of the progressive loss of positional accuracy with time for Landsat 4 are given in Figure 14.

RADIOMETRY AND ATMOSPHERE EFFECTS

To date, no satellite sensor with precision absolute radiometry is available. There is a growing feeling that absolute radiometry is useful in spite of atmospheric problems. This needs to be tested, and the losses in the discovered utility estimated as the radiometry precision deteriorates. Absolute radiometry will interact with pixel size as the area integration varies, and its utility may be quite different as the spectral bandwidth decreases toward the imaging spectrometer parameters. The utility also may be quite different on- and off-axis, as the BRDF and ground slope shadowing vary.

Radiometry is severely affected by the atmosphere, again most critical off axis and with small spectral bandwidths. The effects have been modeled as a path radiance illuminated by single and multiple reflected energy, and is a strong function of the distribution of ground reflectivities within several kilometers of a point in question (Otterman and Fraser, 1979; Dave, 1980; Diner, 1983) However, the small spectral bandwidths may afford a method for estimating and correcting for atmospheric effects. Again, this is a multi-parameter study.

DATA PROBLEMS

The primary data problems which have been voiced are inability to locate appropriate data sets, the general slowness in receiving data, rectification and registration, and the growing size of data sets (for example, the Thematic Mapper images and the upcoming 228 band AVIRIS data). These roadblocks have at best hampered, and sometimes worse, prevented the ability to do research.

Geographic information systems are being developed to solve geographic problems, not necessarily with space data. As such, they will not necessarily be tailored to the space data, but are independent of these data. At the same time, the space data have not been cast into a form best suited to the users' geographic information systems. Various space data are produced for the most part to match the data acquisition/production requirements for the system instead of attempting to make the downstream accession and processing by the user easier.

There is need on the part of the experimenter community to obtain data at various levels, including raw unrectified data (Level 0 Data), rectified (either radiometrically, geometrically, or both) data (Level 1 Data), and various levels of derived or interpreted data (Level 2 and above Data). Data systems of the future will be operating in an archive-to-many-user mode, in which a given data set may be used by various users, potentially at different scales. This and the potential need for raw data argue for the archiving of data in raw form as well as in other forms.

Archive efficiency requires that all necessary data for retrieval, rectification, geocoding, and scaling be readily available with the basic data, for application on retrieval. Some of the extant archives include this necessary data, but most do not.

These and other considerations lead to a set of principles for handling both remote sensing and other related data:

- As soon as practical, provide format guidlines which will place requirements on the archival data to assure archiving of necessary relevant ancillary data.

- If the data are acquired digitally, store them digitally.

- Do a minimum of processing, preferably zero, before archiving.

- Collect and reduce all ancillary data and store with the related archived data, for use in retrieval processing and for transmittal.

- Verify data quality, registration accuracy, and the like, and store this in the archive with the data for inclusion in the transmitted data. This is conceived as a supplier function.

- Provide browsing and cataloguing for the users.

- Provide as retrieval options, rectification, scaling, sub-area selection, and data registration to a standard grid such as UTM, and on request to the user's grid.

- Define early-on, a philosophy for nesting data of various resolutions, to provide a framework for data operations.

It is recognized that, unfortunately, most of the extant archives do not contain data with the above characteristics.

These requirements are not new; they have been discussed repeatedly in some form or another [for example, Simonett,1979; CODMAC I report, 1982] over an extended period. NASA now has in operation or planned a series of Pilot programs based on broad discipline lines (Oceans, Climate, Planetary, and Land). These, when fully acheived, should fulfill most of the desiderata above, at least for the group of investigators served.

Part of the task of an information potential study is to estimate to what degree research (and operational use) has been hampered by the lack of such systems, and to what heights information extraction might rise if the data system presented no roadblocks. Would minimizing data latency increase research effort? Would direct broadcast of selected data instead of funnelling it all through an archive be useful? How about transmission of information, i.e., processed data, instead of or in addition to the raw data?

BUILDING FOR THE FUTURE

Great solutions do not come from small problems. Large problems may not be considered because of many small roadblocks. Let us now look at the forest instead of examining the trees.

The basic proposition will be that large problems are interdisciplinary, interdisciplinary research tends to be on large problems, that there currently is little large-scale interdisciplinary work occuring, and that the full potential of remote sensing will be most eviedent as large, interdisciplinary problems are tackled. Therefore, let us consider several which have been discussed.

The characteristics of these major programs are that they are global and long range. Global problems require global models, which for the most part are not available or are inadequate. Global models, in turn, require global data for their solution. Utilization of global data requires that they be planned to be sensed, then located and assembled. The global modeling problem is the same as the system modeling problem discussed in Figure 3, with the bottom line being that even if the models were formulated, currently the data to solve them are not available.

Global Carbon Dioxide cycle - Several large models are required: Global atmospheric circulation, interaction with the ocean, effect of terrestrial vegetation, release from fossil fuels, other sources of natural CO2, biological productivity, relation to other global chemical (P, N, S) cycles, to name several. For this discussion, the thrust is whether remote sensing can provide the necessary data to solve these models, and what is necessary for an adequate information system. This will require knowledge of circulation patterns, latitudinal temperature variations, forest distributions by types and their rates of change, evaluation of cultural practices as they affect forest product disposition, distribution of carbon in various forest regimes, carbon transfer at the air-sea interface as pH, temperature, and sea state vary, ocean precipitation of carbonates, fossil fuel practices, and others. The point here is the interdisciplinary nature of the problem and the wide gamut of data required.

Acid Rain and Pollution Dispersion - Again, circulation patterns are required. In addition, knowledge will be required of a number of individual parameters: fuel components and their dispersion depending upon energy practices, manmade sources such as automotive combustion, possible natural sources, effects on soil pH and water pH, efficacy of natural buffering, the identification of specific sources by trace components, relative importance of S and N. Can remote sensing of trace materials be of assistance? Given the problems of repeat coverage due to orbit constraints, are better orbits possible? How about a synchronous polar orbit repeatedly going across Kansas with trace pollutant sensors? Could laser-based absorption-line detectors be of use? If you really set out to solve this problem, what would you do, and what remote sensing would you call for?

Biogeochemical Cycle - The very foundation of our existence. To quote from an AIAA [1977] report: " In the years ahead, we will be able to predict how much food the Earth will produce while most of that potential food is still 'on the hoof' or in the ground - this will help us to feed the hungry. We will be able to know in advance how much fresh water, timber, oil, and metallic minerals we can safely consume - this will help us to harmonize growth. ... " Again, we require an interdisciplinary approach (if we strip mine Montana for the coal, how soon can the wheat and cattle culture again become practical?), the use of global models, and a wide variety of data. We are concerned with both aquatic and terrestrial cycles and their vitality with changes in their environment - upwellings, water temperature and other coastal processes, water circulation, el Nino effects, any interactions with the global CO2 problem, effects of soil pH, rainfall (acid or not), hydrology and water table problems, primary productivity in the wetlands, leaf chemistry, and the nutrient value in crops and the development of crops to suit environmental conditions - for starters. Figure 15, from a recent NASA study on Global Habitability [NASA, 1983], illustrates the interdisciplinary nature of the problems and suggests the utility or the remote sensing component. If we really want to aid in the understanding of the biogeochemical cycle and the renewable resources problems, how could coordinated (across disciplines) remote sensing aid in solving the present models and allow new models, now untenable, to be developed?

Deforestation, Desertification, and Habitability - Remote sensing has aided in the understanding of the magnitudes of these problems. Again, the problem is interdisciplinary - soil conditions, general rainfall and temeprature conditions, population pressure and cultivation practices, forest stripping for fuel, wood products, or for other uses of the land, land suitability for other uses, changes in rainfall due to changes in vegetative cover are some of the factors involved. This problem interacts with and uses many of the same data as the biogeochemical cycle problem, the global CO2 and weather and climate problems. Worldwide vegetative maps can be assembled, showing changes over time. Worldwide data bases of temperature, rainfall, and other parameters can be assembled. Many of the problems are largely social problems. How can the social sciences benefit from remote sensing?

Weather and Climate Monitoring and Prediction - This, of course, has been a major contribution of remote sensing. There is no need for an apologia for this use. The emphasis for this discussion is the interaction of this discipline with the others - the use of global circulation and precipitation models with the global CO2 and habitability problems, for example. Recent work by Tucker has shown the potential of correcting Landsat images by flagging areas of high cirrus which distort the normal spectral responses. Can the data distribution techniques developed for this discipline be used for the others? Should modern data storage techniques be used to retain more of the old weather data for historical studies?

Other major problems could be discussed, such as: global navigation, global sea conditions and the effects on shipping, ice processes, global topographic mapping, physical oceanography, basic geodesy. All have been, and will be, aidid by remote sensing and contribute to the information derived from it.

PARTING THOUGHTS

The information potential of remote sensing has been discussed from three viewpoints (in the reverse order): large scale, interdisciplinary problems, the limiting factors of a number of the sensed parameters, and the optimization of a total system if the clientele problems can be defined.

The data can become available, and the ground information systems developed, to allow the generation of globally consistent data sets of many parameters such as land cover, temperature, ocean elevation and other ocean effects, and weather patterns. The global coverage allows error detection and potential correction, and global analyses.

Modern information systems can be used to locate data, inform users of the access procedures and who is working on given data. All of these capabilities are not yet implemented consistently, but could be as their need is shown.

Ground processing is beginning to produce geocoded data, relieving the user of this generally non-productive but necessary operation and allowing the assembling of coordinated sets of disparate data. Remotely sensed data are beginning to be related to data from other sources in modern information systems. Computer analysis workstations are increasing in capability, allowing the single user to perform analyses previously requiring major installations. Data transmission rates are increasing, allowing rapid interchange of data and analysis results. The wider availability of disparate data is making possible the development of more complex models, knowledge-based analyses and data base access methods.

The potential of remote sensing in contributing to both research and "practical" applications is truly only beginning to surface. Wise planning must assure continuation of the data sources and the growth of the analysis and applications capabilities. The technical community must not be prematurely pressed to show profitable use of the data. The applications will develop at their own pace, provided that there are reasonable expectations of continued data availability.

ACKNOWLEDGEMENT

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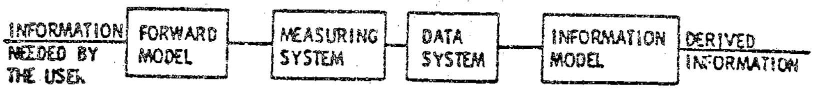


Figure 1. Information System Overall Diagram

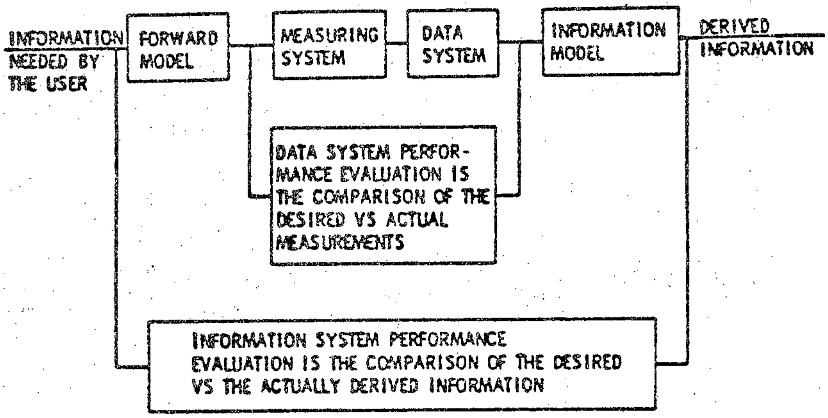


Figure 2. Performance Evaluation can occur at either the Data System or Information System level.

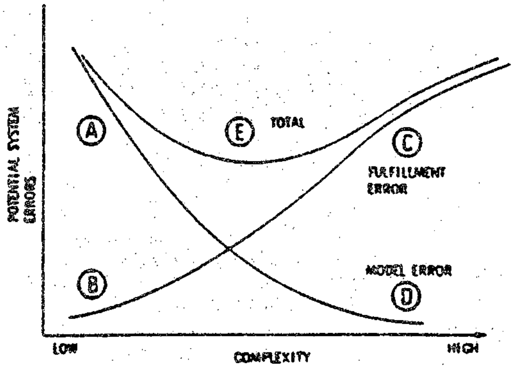


Figure 3. Model and System Complexity Optimization.

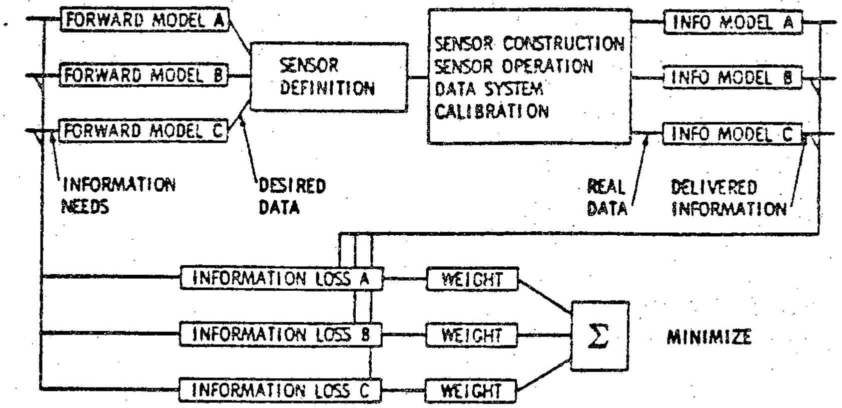


Figure 4. Design Model for Information System Optimization

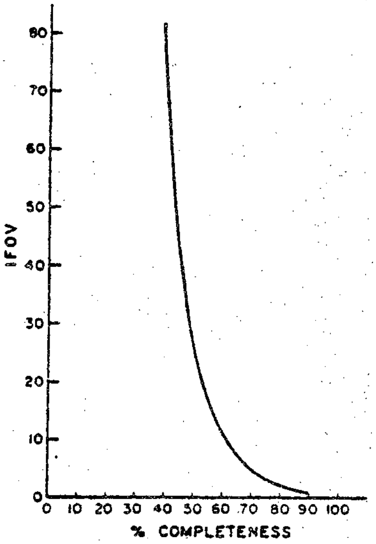


Figure 5. IFOV vs. completeness (From Welch and Petrie)

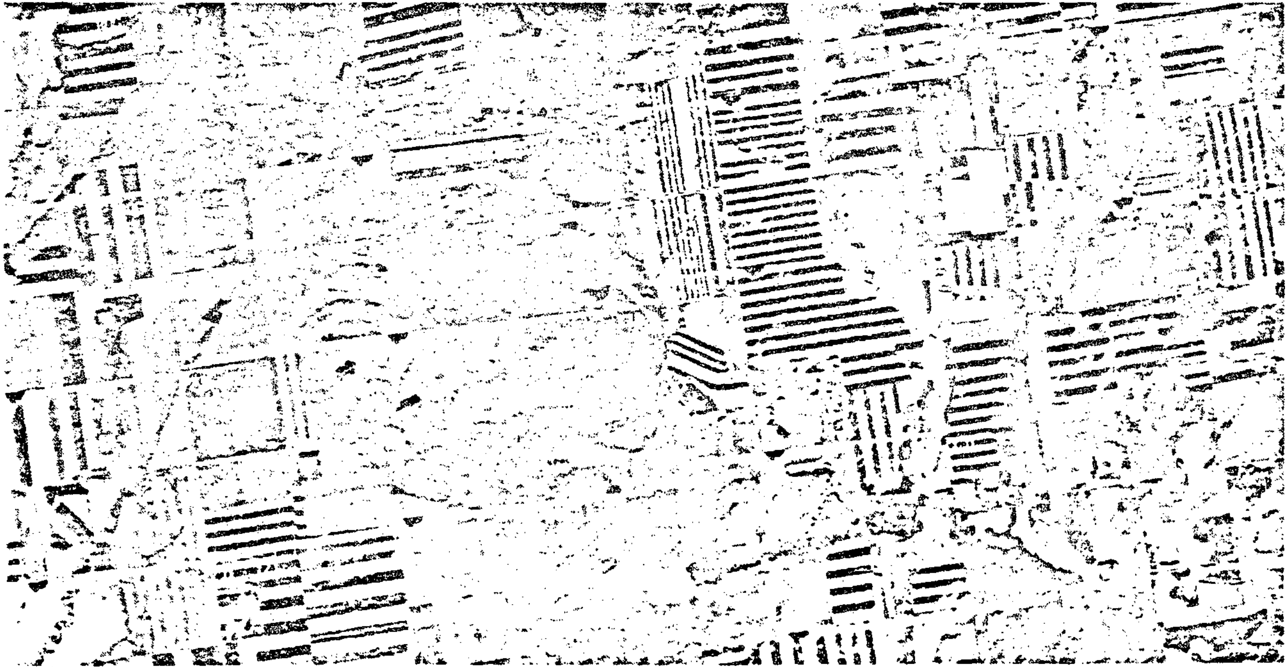


Figure 6. Strip-fallow plowing makes good test targets!

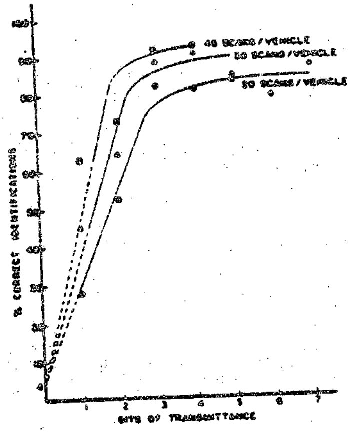
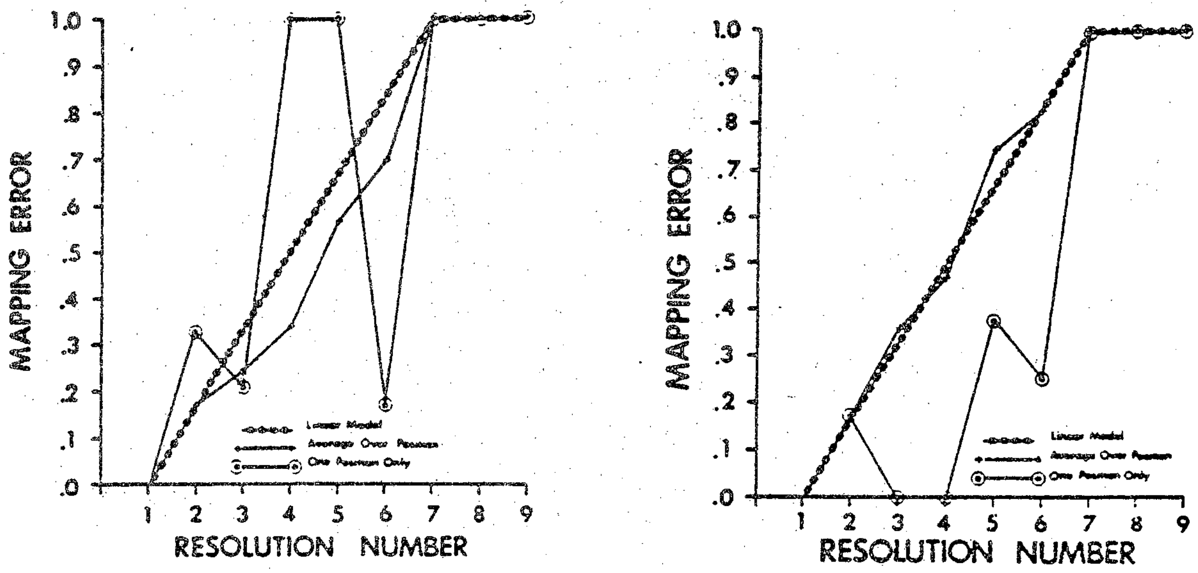


Figure 7. Object Recognition as a function of number of scans per object. (From Scott and Hollanda)



(a)

(b)

Figure 8. Mapping Errors for Selected Resolutions when the mapping unit is a: (left) circle, (right) rectangle. (From Wehde)

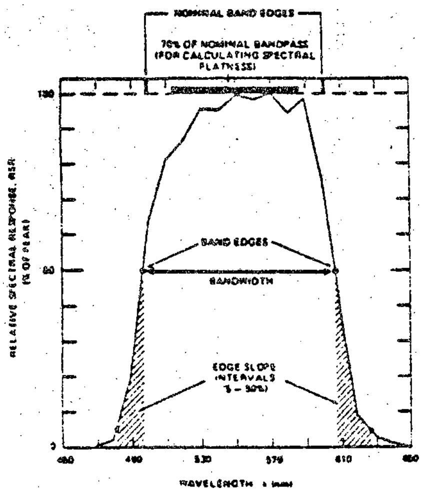


Figure 9. Typical Landsat spectral band shape. (From Alford and Barker)

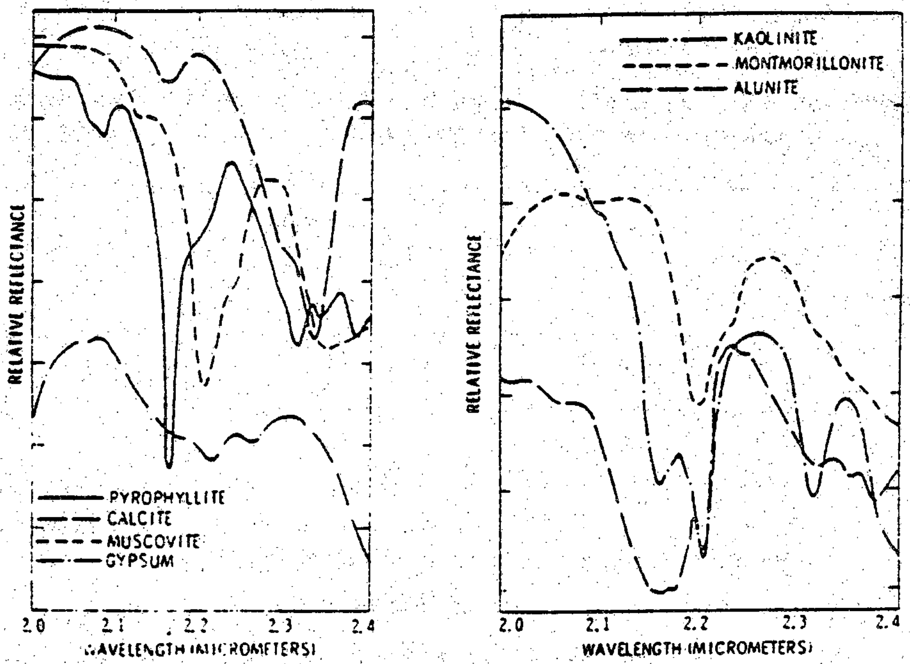


Figure 10. High resolution Laboratory Spectra of minerals exhibiting overtone vibrations in the 2-2.5μm region. (After Hunt and Ashley)

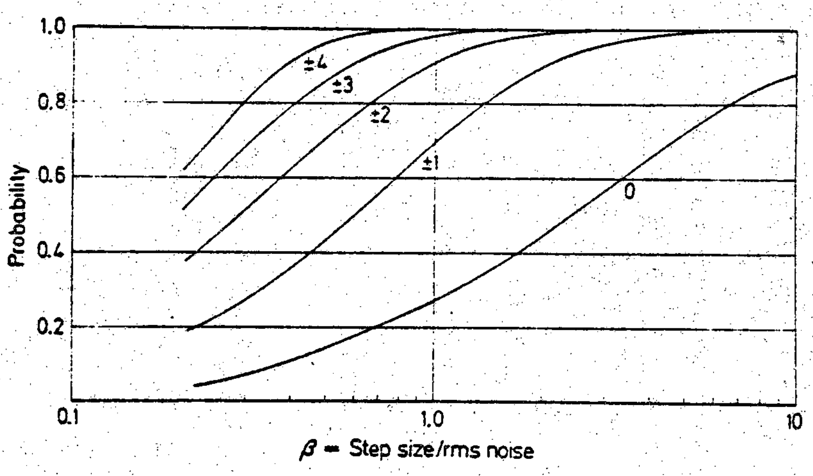


Figure 11. Given two signals which have been perturbed by Gaussian noise of value equal to σ. Each is quantized to the same number of bits. The curves give the probability of correctly determining the true difference in the two levels within ±0, ±1,...±4 (inclusive) DN as function of the ratio β = step size/σ

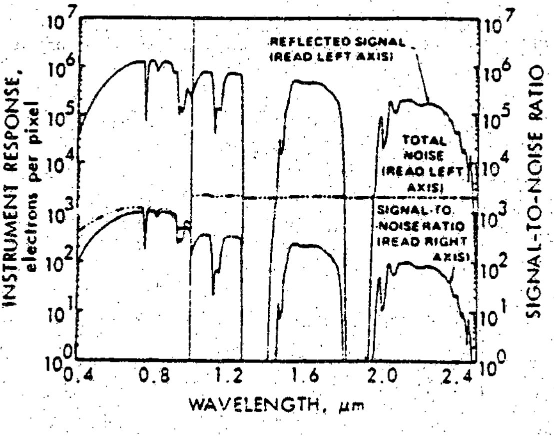


Figure 12. Signal to noise ratio calculated for SISEX. (From Wellman et al, 1982)

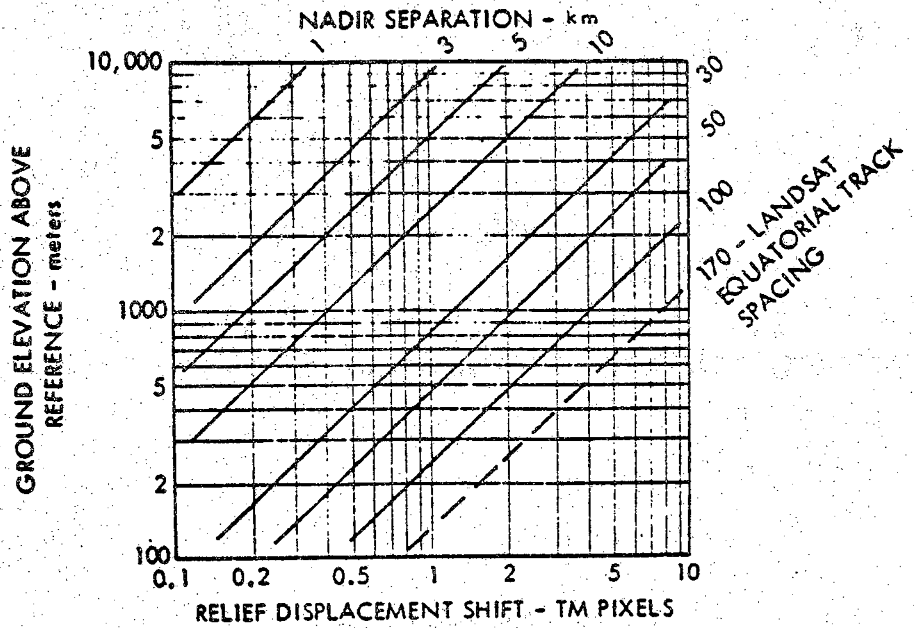


Figure 13. Relief Displacement Effects for Various Nadir Separations

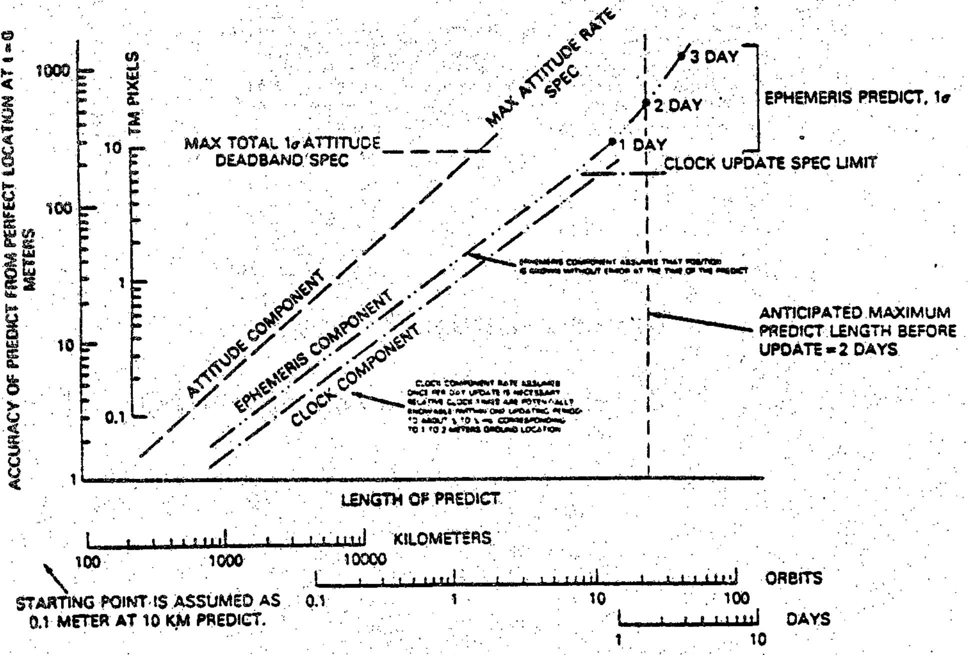


Figure 14. Potential Location Uncertainty Relative to a Perfectly Determined Position at t=0 Landsat D

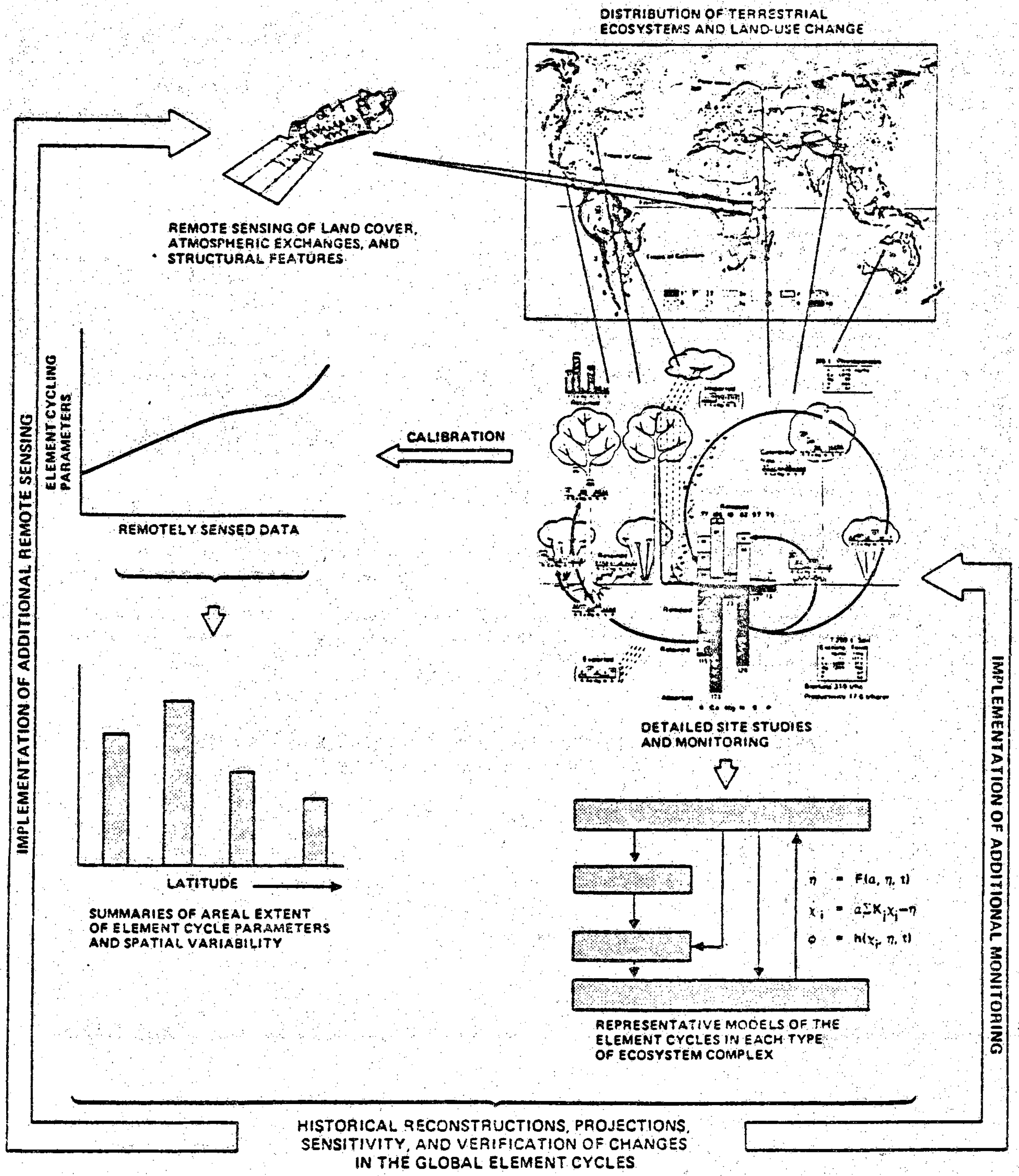


Figure 15. Relationship of Biogeochemical Cycling Research Areas (From NASA, 1983)

APPENDIX E: Hovis Presentation

Comments of Warren A. Hovis Concerning

Geostationary Observations of Earth Resources

Remote sensing for earth resources has traditionally been done from satellites in near polar orbit at altitudes less than 1000 kilometers. In the early days of remote sensing, as with Landsat-1 and those spacecraft that followed it, such orbits were necessary because the scanning mechanism was principally mechanical and relied upon the motion of the spacecraft to provide scanning in one direction. Now that silicon diode arrays are available with a very large number of detectors, it is feasible to reconsider geostationary or near geostationary satellites for remote sensing, and reconsider the advantages and disadvantages of such satellites.

Disadvantages

The obvious disadvantage of a geostationary spacecraft is that it must fly at an altitude of 38,000 kilometers above the Equator, and its coverage is limited to the portion of the earth that can be viewed from one particular longitude in the geostationary range while it is, in fact, geostationary. Another disadvantage is the limitation of area coverage. Limited area coverage is not as serious as it may seem since geostationary spacecraft can be moved from one position in the geostationary ring to another with modest capability such as now exists on the GOES spacecraft. For instance, an imager that was viewing the United States during the summer growing season from a longitude of approximately 100 degrees west could be moved during the northern hemisphere winter to another location where it could view an area such as Australia or Argentina. Such movement has already been carried out with the GOES spacecraft of NOAA as part of the GARP program.

The disadvantage of distance from the target can be compensated for by the fact that the spacecraft velocity relative to the target is zero in the geostationary mode, and one can compensate for distance with time. Since the polar orbiting low altitude spacecraft have a sub-satellite velocity of approximately 7 kilometers per second, data must be taken from the spacecraft as it crosses the target at this velocity, hence, it must be taken in a very short period of time.

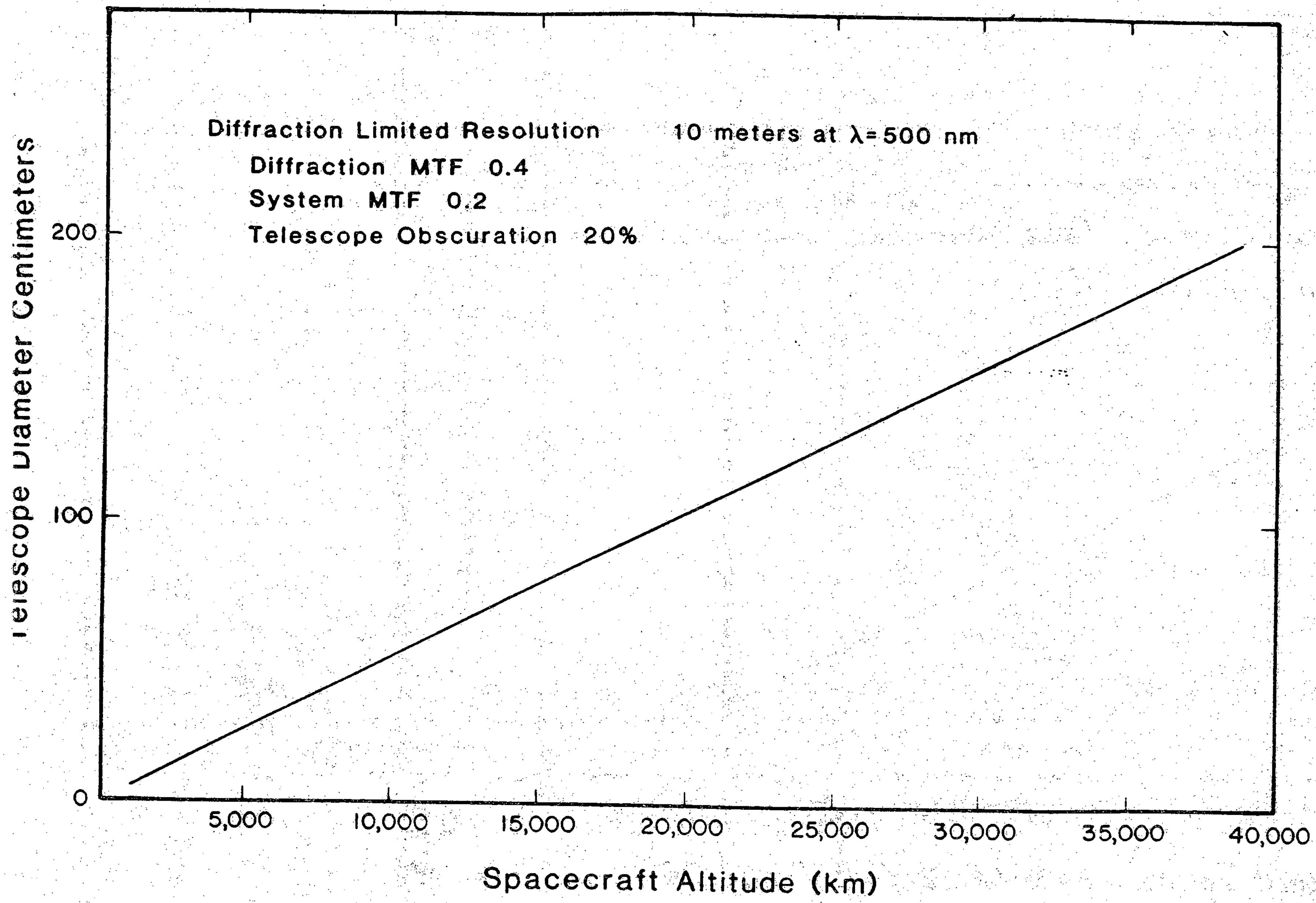
Advantages

A geostationary spacecraft has no such limit on time and is limited principally by the hours of sunlight. For instance, one could scan from the Gulf coast to the northern border of the United States, utilizing an hour or even two, whereas the polar satellite makes the same transit in a matter of four or five minutes. Spatial resolution is limited by the size of the collector mirror as shown in the attached graph where the telescope size is calculated to be 200 centimeters for a 500 nanometer wavelength and 10 meter resolution at the surface. Obviously, if one backs off to less ambitious resolutions such as 50 meters, the telescope size drops down below a meter with reasonable resolution available from the 40 centimeter telescopes that are now being produced for the VISSR program in NOAA.

Another advantage of the geostationary spacecraft is that each area is viewed from the same position each time it is scanned, facilitating overlay of images from successive scans in one day, or from successive days. By this technique, one can build up a reasonable approximation of a clear weather image by adding together the clear portions from images taken on the same day or on successive days similar to the technique utilized for ocean temperature measurements by NOAA in the Global Operational Sea Surface Temperature Computation. With such frequent coverage, the severe problems encountered with a low altitude spacecraft with repeat time of 15 days and possibility of cloud cover are, to a large degree, overcome.

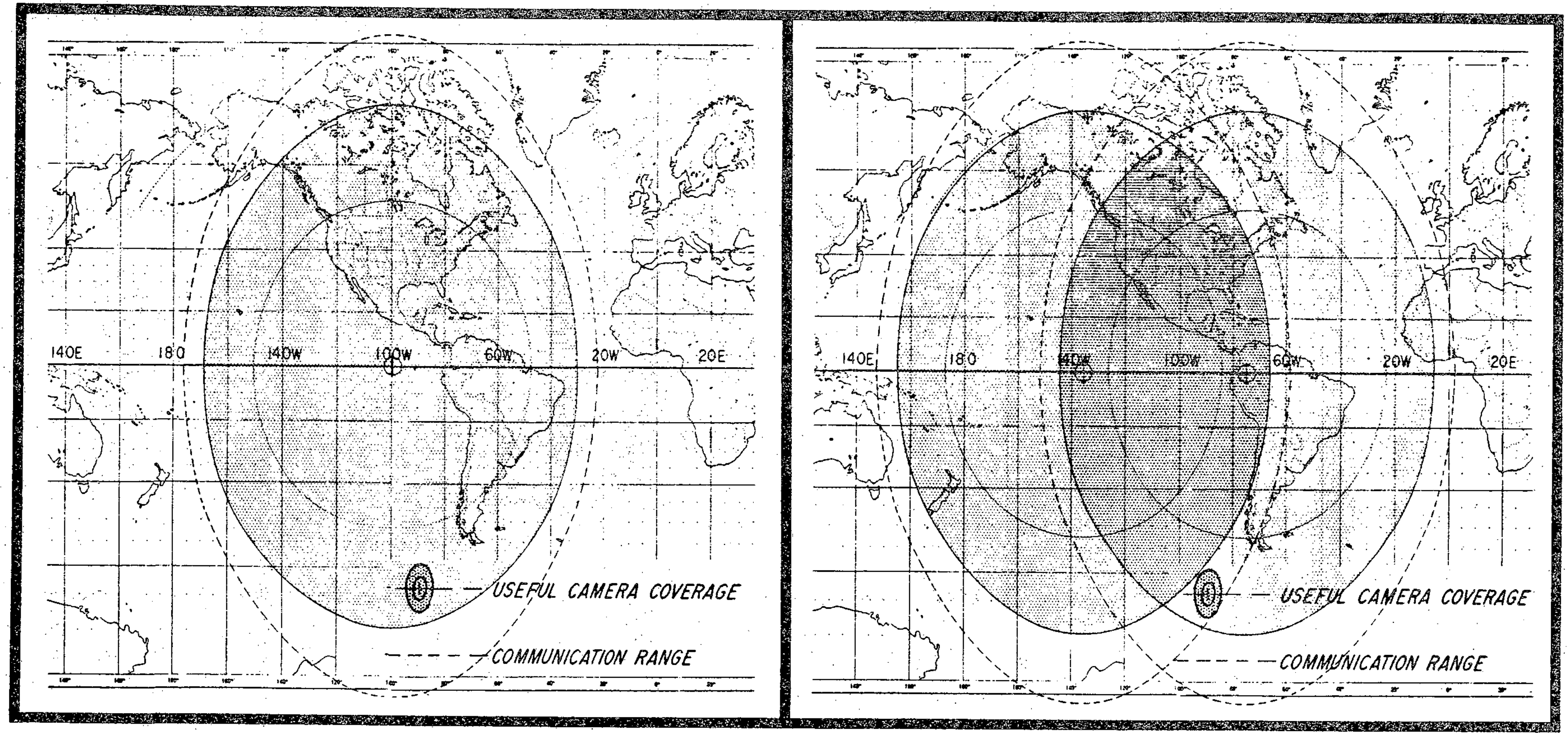
Another advantage of the geostationary sensing is that, since it is done at a slower rate, the instantaneous data rate can be far slower than the present rates of the Landsat that are approaching 100,000,000 bits per second. This, in turn, makes the necessary ground station much cheaper since the hardware to receive and record 100,000,000 bits per second is much more expensive than that which would be necessary for a few million bits per second. It should also be noted that geostationary spacecraft with steerable platforms can be programmed so that they do not have to scan from horizon to horizon, but scan only the area of interest. For example, the GOES/NEXT sounder and imager are to be specified to cover an area of 1000 x 1000 kilometers, 3000 x 3000 kilometers, or the whole earth disk from 60 degrees north to 60 degrees south, with the time of coverage varying according to the area. One could even program the coverage throughout the day by looking at the GOES cloud cover imagery, and program the satellite to view the areas that are clear. The GOES cloud cover imagery is available every half an hour, and could allow high efficiency strategies to be developed for utilization of such a scanner when in range of the GOES imagery. It should be noted that in other areas of the world, such as Europe and Africa and the Far East to include Australia to Japan, there are other geostationary spacecraft owned by other nations that might be utilized on a cooperative basis to produce the same efficiency of scanning.

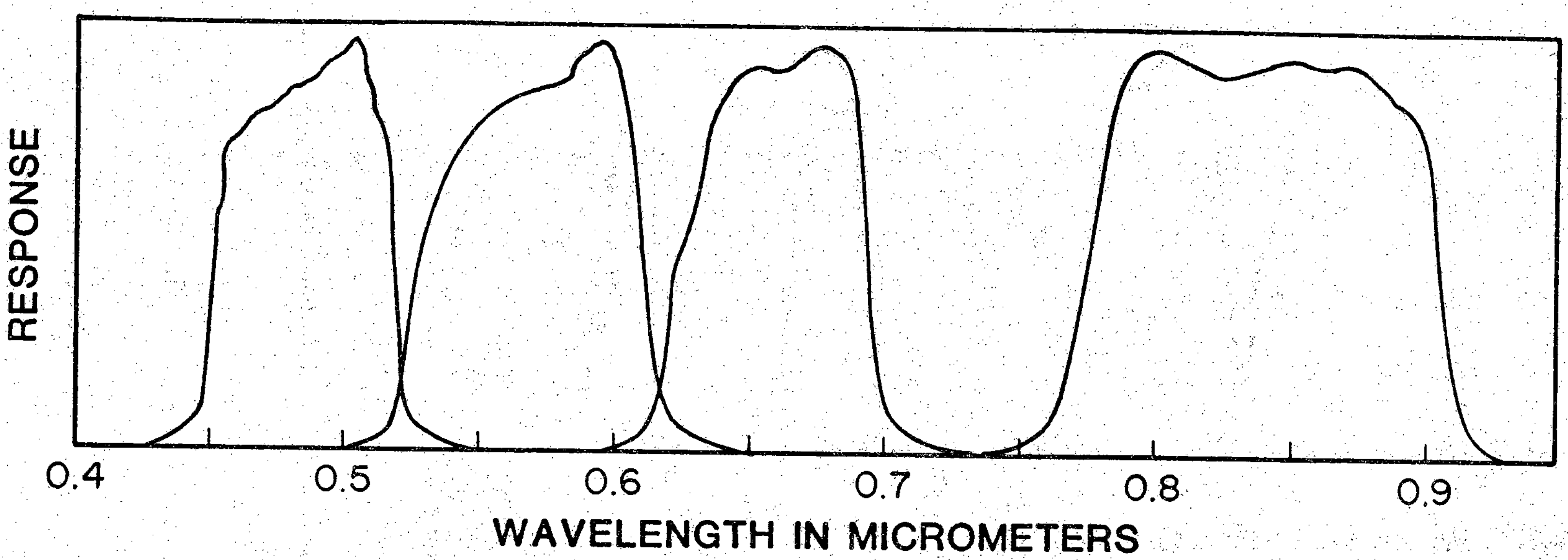
Obviously, to utilize the advantages of a geostationary spacecraft, a large and expensive instrument will have to be developed, but the technology exists now to do such development, and the total cost when compared with the polar satellites, and the advantage of frequent coverage, may outweigh the cost of developing a new sensor.

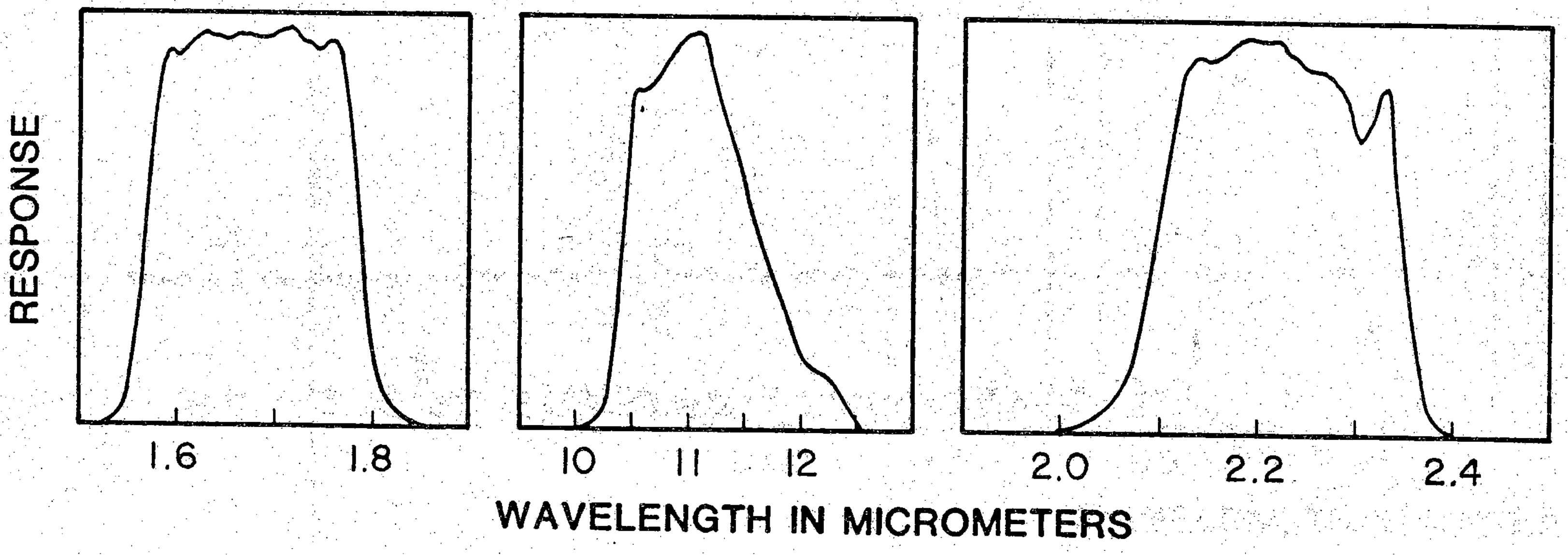

Diffraction Limited Resolution 10 meters at λ=500 nm
Diffraction MTF 0.4
System MTF 0.2
Telescope Obscuration 20%
Telescope Diameter Centimeters
0
100
200
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Spacecraft Altitude (km)

GOES Geographic Coverage

One Satellite Two Satellites




RESPONSE
0.4
0.5
0.6
0.7
0.8
0.9
WAVELENGTH IN MICROMETERS


RESPONSE
1.6
1.8
10
11
12
2.0
2.2
2.4
WAVELENGTH IN MICROMETERS

	HIGH RESOLUTION POINTABLE IMAGER (HRPI)	HIGH RESOLUTION IMAGING INSTRUMENT (HRV)
SPATIAL RESOLUTION	10 METERS	20 METERS MULTI SPECTRAL 10 METERS PANCHROMATIC
SWATH WIDTH	48 km	60 km (2 Sensors with overlap 117 km)
SPECTRAL BANDS	0.5–0.6 micrometers 0.6–0.7 micrometers 0.7–0.8 micrometers 0.8–1.1 micrometers	Multi Spectral 0.5–0.59 micrometers 0.61–0.68 micrometers 0.79–0.89 micrometers Panchromatic 0.51–0.73 micrometers
OFF Nadir View	±10° in 1° steps	±27° in 0.6° steps

NASA Linear Array Scanner

Channel	Center Wavelength	Width	Spatial Resolution
1	470 nm	20 nm	15 m
2	560 nm	20 nm	15 m
3	670 nm	20 nm	15 m
4	880 nm	20 nm	15 m
5	1240 nm	20 nm	30 m
6	1550 nm	20 nm	30 m

Swath 30 km

Vehicle Shuttle end of 1987

Data Transmission TDRSS 42 Mb/sec

TABLE 1

Multispectral Electronic Self Scanning Radiometer (MESSR)

Spectral Bands

0.51 - 0.59 micrometers
0.61 - 0.69 micrometers
0.72 - 0.8 micrometers
0.8 - 1.1 micrometers

Spatial Resolution ~ 50 meters
Swathwidth ~ 100 km

Imagers on NOAA and NOAA-NEXT

NOAA

Channel	Resolution
0.58-0.68 µm	1.1 km
0.725-1.00 µm	1.1 km
3.55-3.93 µm	1.1 km
10.3-11.3 µm	1.1 km
11.5-12.5 µm	1.1 km

NOAA-NEXT

Channel	Resolution
0.58-0.68 µm	1.1 km
0.82-0.87 µm	1.1 km
1.57-1.78* µm	1.1 km
3.53-3.93* µm	1.1 km
10.3-11.3 µm	1.1 km
11.5-12.5 µm	1.1 km

* Only one of two channels may be transmitted. Channel selected for type of target.

Imagers on GOES and GOES-NEXT

GOES-NEXT		GOES-[redacted]	
Channel	Spatial Resolution	Channel-	Spatial Resolution
0.55-0.75 µm	1 km	0.54-0.7* µm	1 km
3.80-4.00 µm	4 km	10.5-12.6 µm	10 km
6.50-7.00 µm	8 km		
10.2-11.2 µm	4 km		
11.5-12.5 µm	4 km		

* 0.7 micrometer cut off variable up to 0.1 micrometers.

Note - Water vapor imaging done on GOES with sounder channels.

Sounding and imaging cannot be concurrent on GOES.

Will be concurrent on GOES-NEXT.

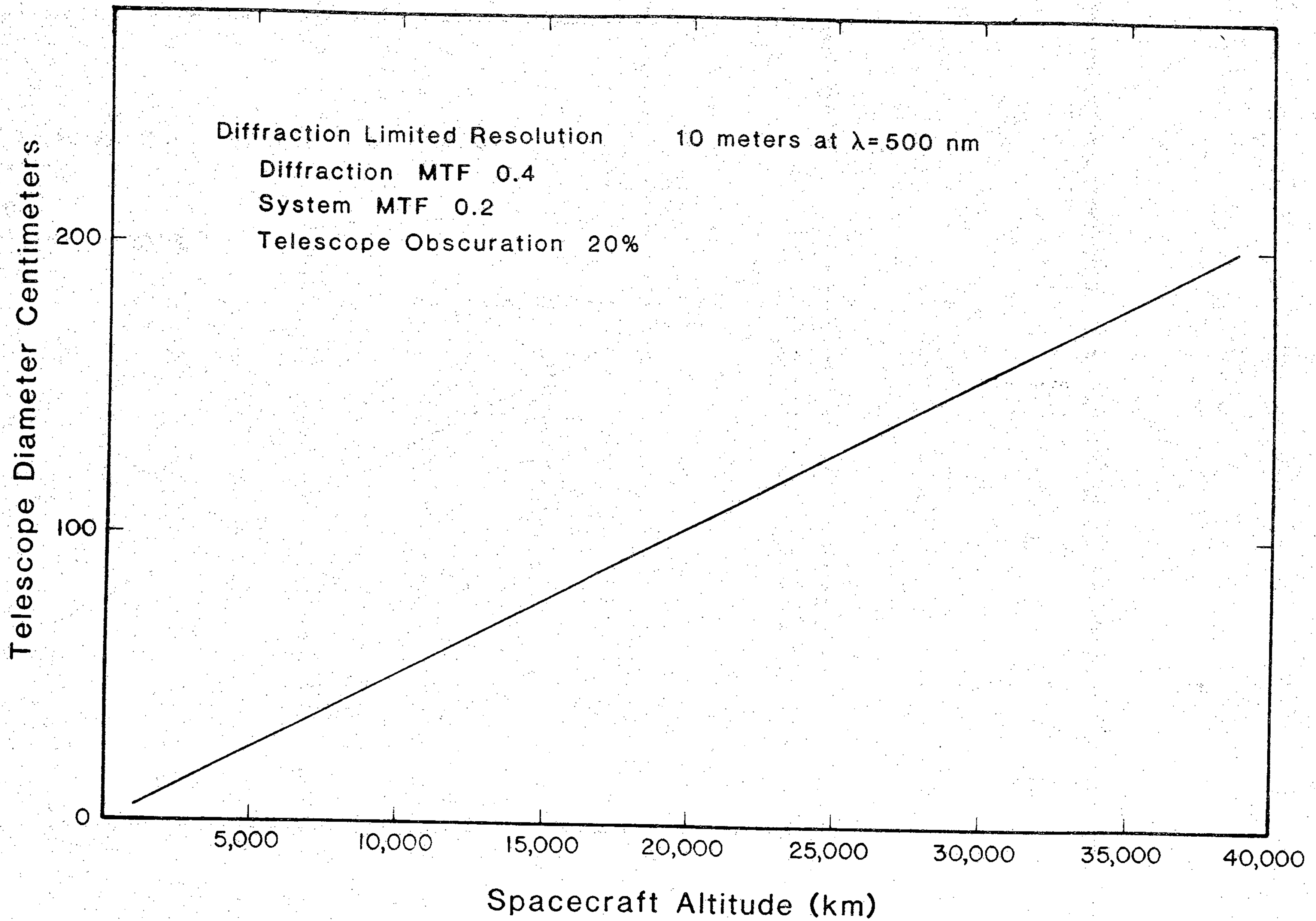
NASA Linear Array Scanner

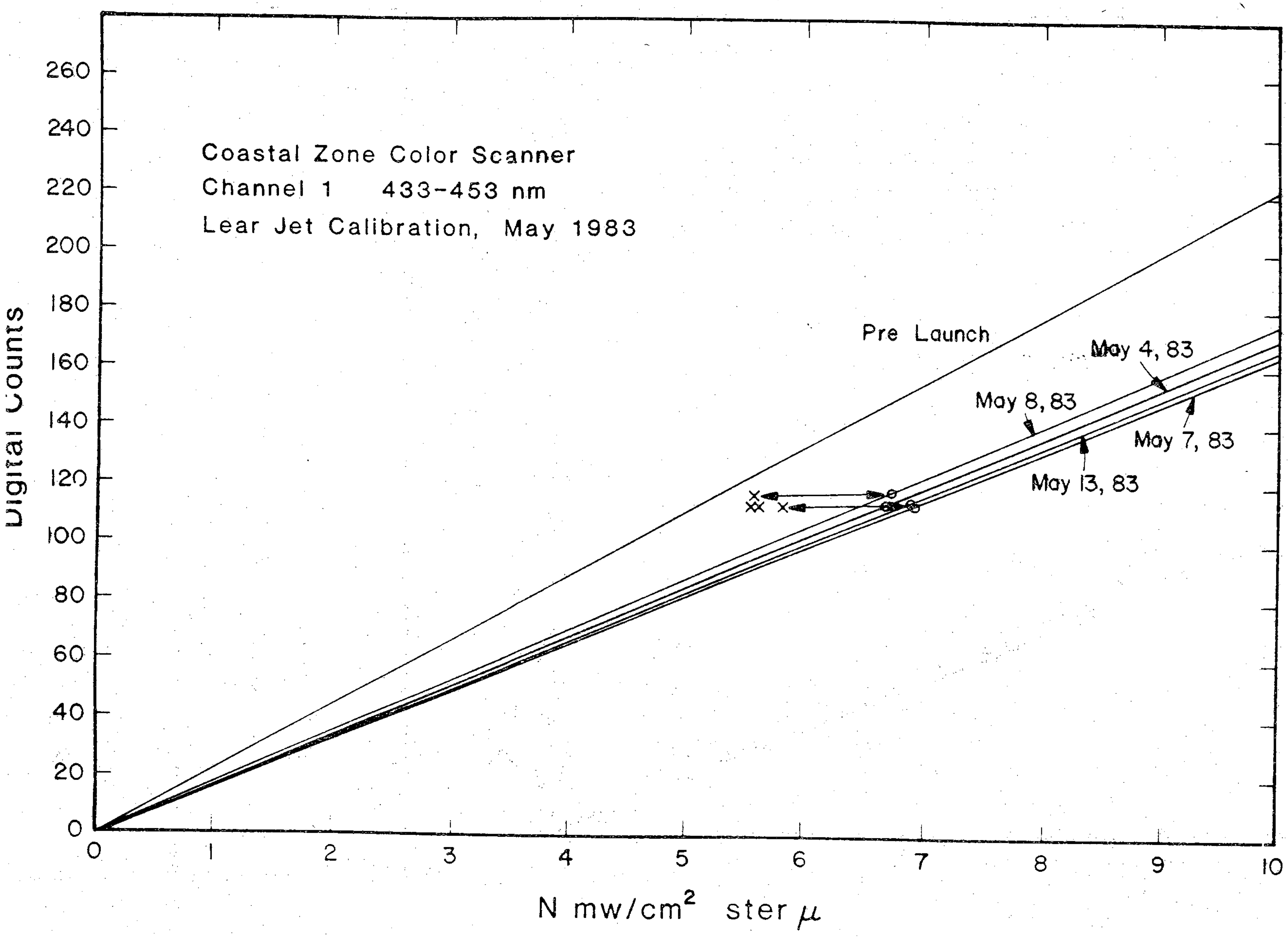
Channel	Center Wavelength	Width	Spatial Resolution
1	470 nm	20 nm	15 m
2	560 nm	20 nm	15 m
3	670 nm	20 nm	15 m
4	880 nm	20 nm	15 m
5	1240 nm	20 nm	30 m
6	1550 nm	20 nm	30 m

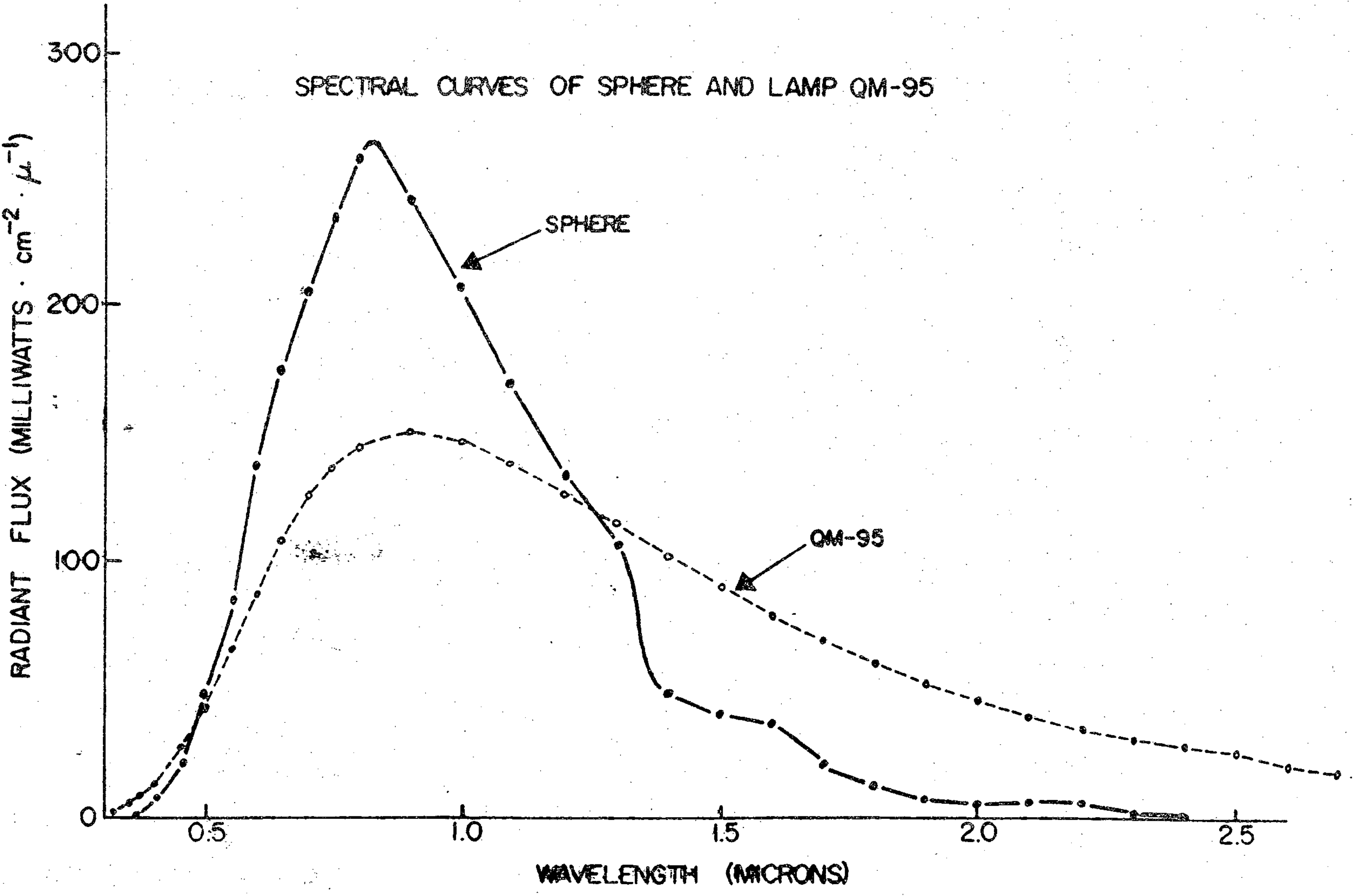
Swath 30 km

Vehicle Shuttle end of 1987

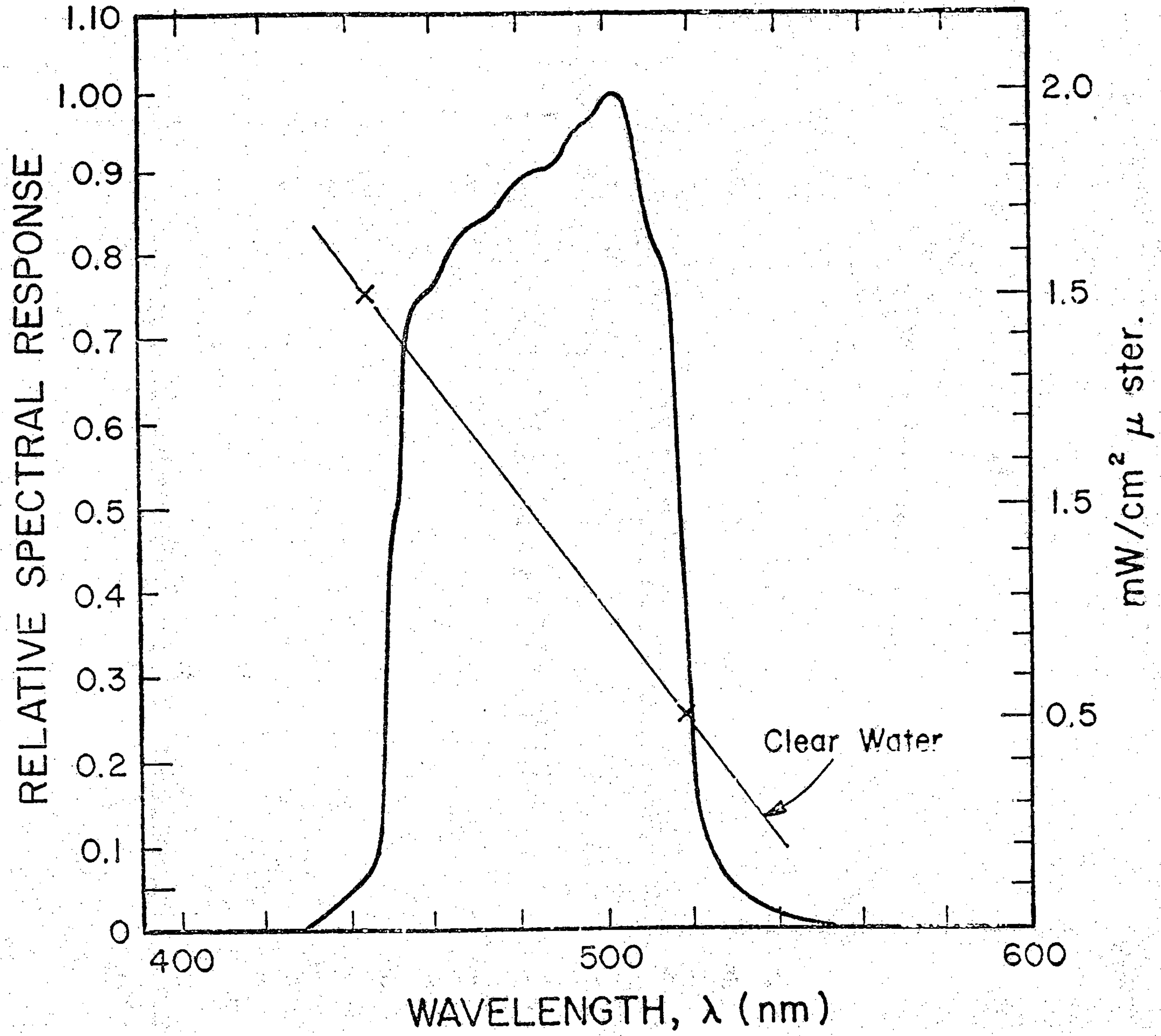
Data Transmission TDRSS 42 Mb/sec


Diffraction Limited Resolution 10 meters at λ=500 nm
Diffraction MTF 0.4
System MTF 0.2
Telescope Obscuration 20%
Telescope Diameter Centimeters
0
100
200
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Spacecraft Altitude (km)

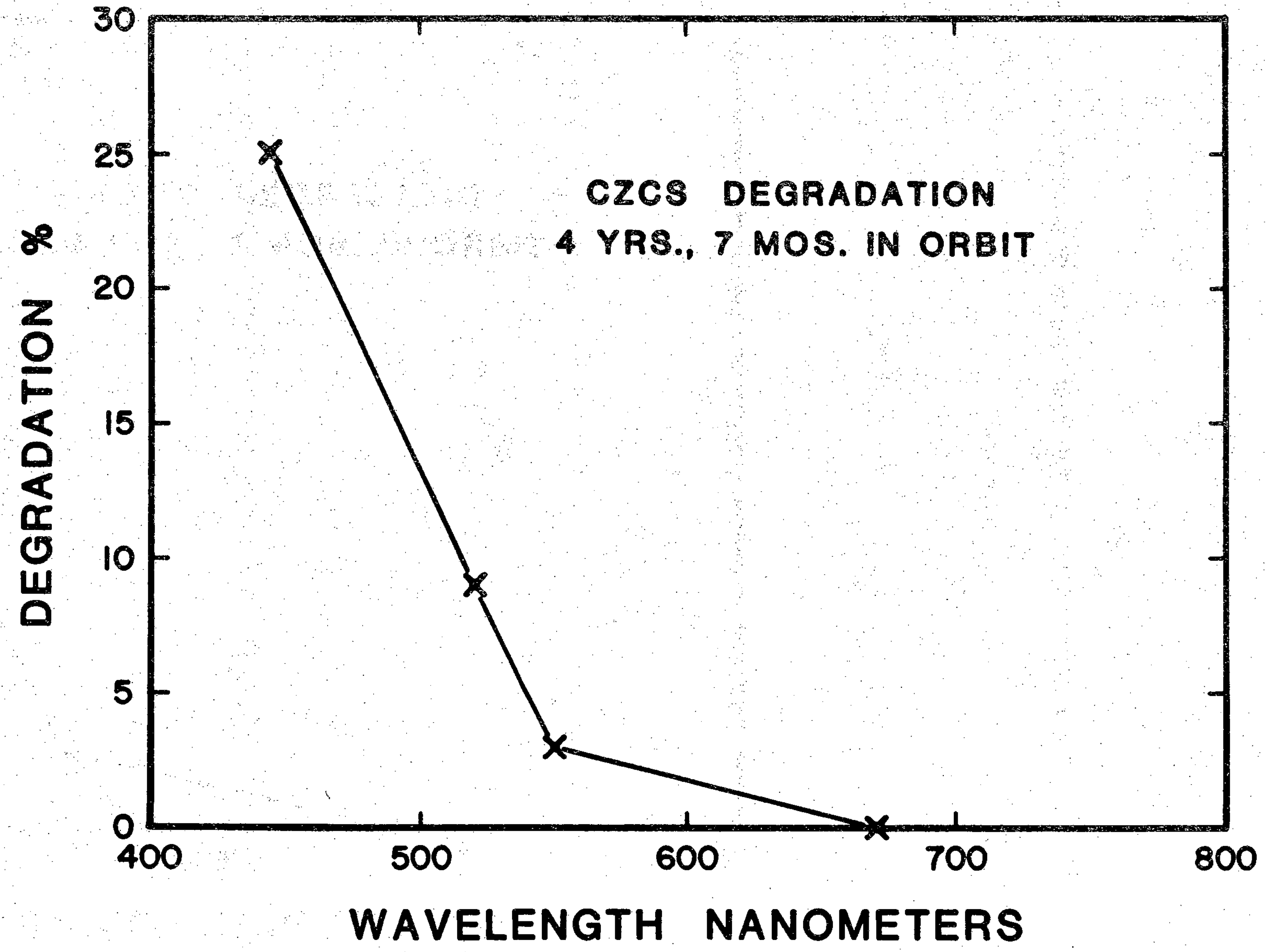

Coastal Zone Color Scanner
Channel 1 433-453 nm
Lear Jet Calibration, May 1983
Digital Counts
0
20
40
60
80
100
120
140
160
180
200
220
240
260
0
1
2
3
4
5
6
7
8
9
10
N mw/cm^2 ster μ
Pre Launch
May 4, 83
May 8, 83
May 7, 83
May 13, 83

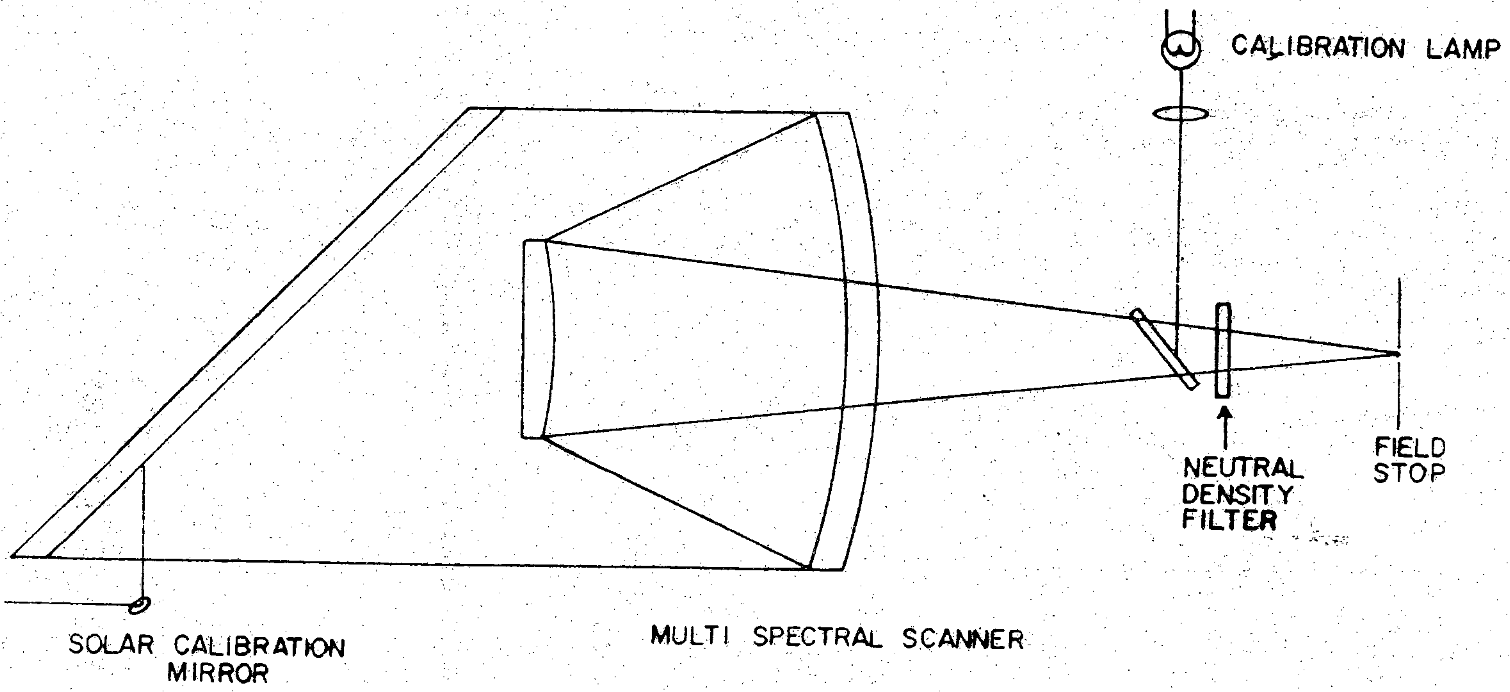


Spectral Radiant Emittance of Six-Foot Spherical Integrator and of One Standard Lamp #QM-95

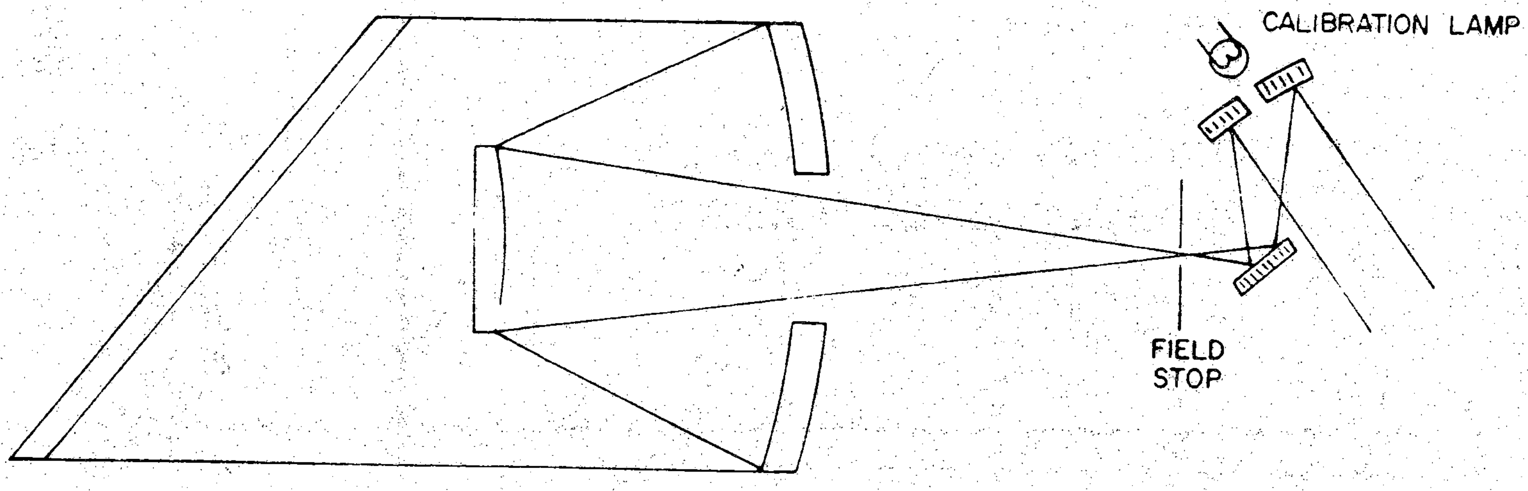


1.10
1.00
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RELATIVE SPECTRAL RESPONSE
400
500
600
WAVELENGTH, λ (nm)
2.0
1.5
1.5
0.5
mW/cm² μ ster.
Clear Water


CZCS DEGRADATION
4 YRS., 7 MOS. IN ORBIT
DEGRADATION %
0
5
10
15
20
25
30
400
500
600
700
800
WAVELENGTH NANOMETERS

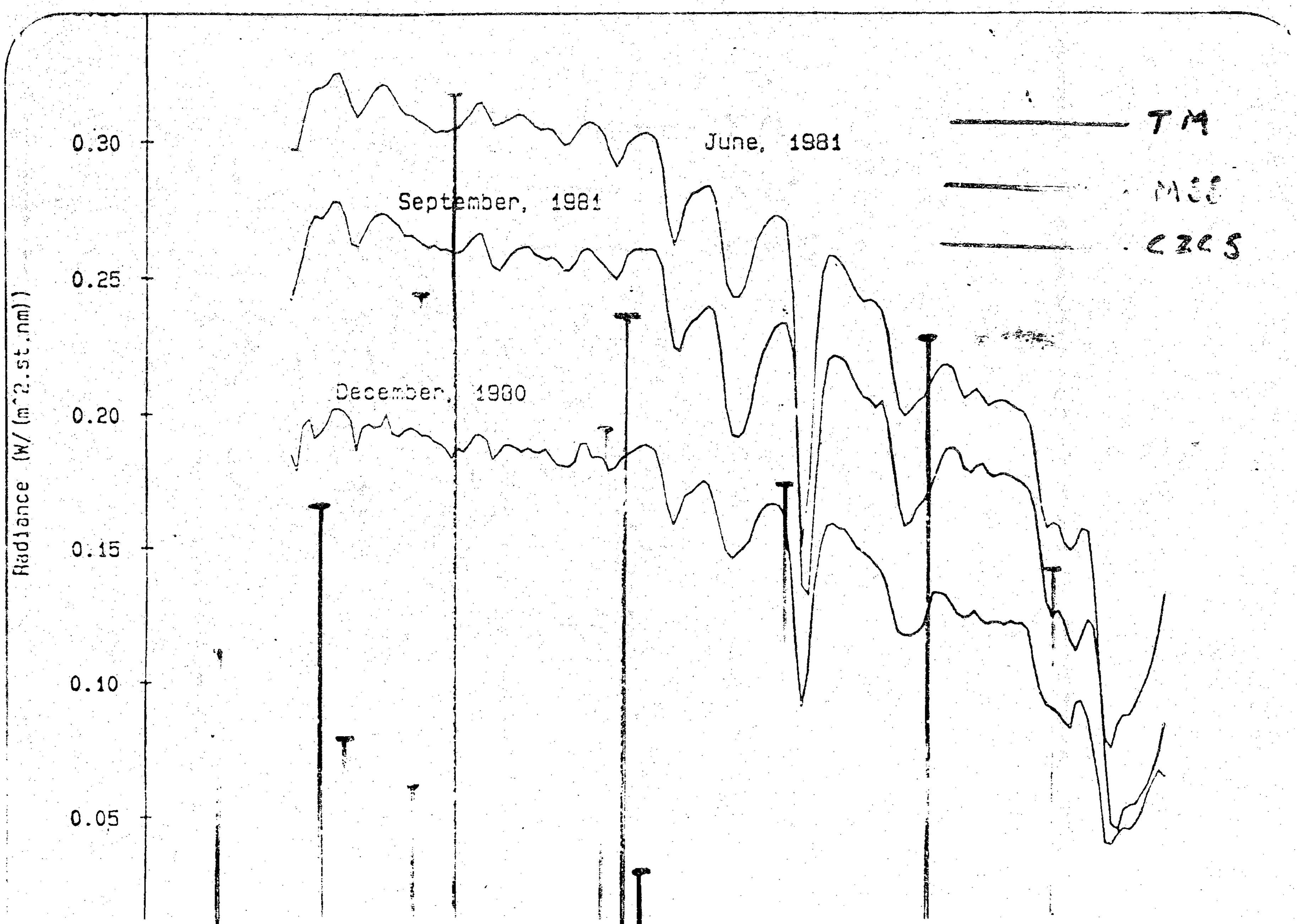


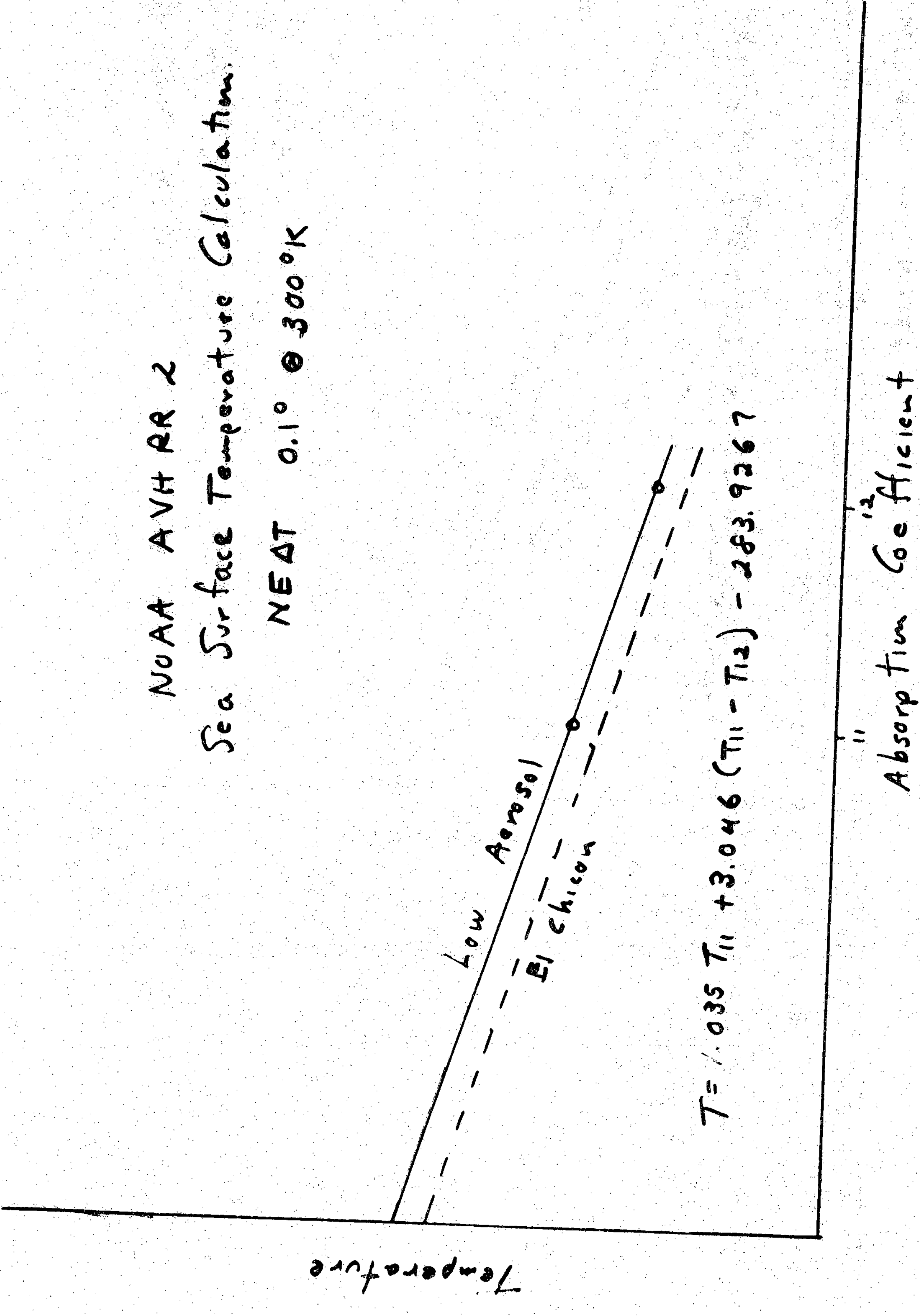
MULTI SPECTRAL SCANNER



COASTAL ZONE COLOR SCANNER

CALIBRATION SCHEMES MSS AND CZCS


Radiance (W/(m^2.st.nm))
0.30
0.25
0.20
0.15
0.10
0.05
June, 1981
September, 1981
December, 1980
TM
MSS
CZCS



NOAA AVHRR 2

Sea Surface Temperature Calculation.

NEΔT 0.1° @ 300°K

APPENDIX F: Carver Presentation

TECHNOLOGY DRIVERS FOR SPACEBORNE IMAGING RADAR

K. R. CARVER
New Mexico State University

February, 1984

SPACEBORNE IMAGING SENSOR REQUIREMENTS OF THE '90s

SPECTRAL

- microwave (L, C, X - bands)
- millimeter
- Thermal IR (10 - 12 µm)
- Short-wave IR (1 - 2 µm)
- Visible/Near IR (.45 - 1 µm)

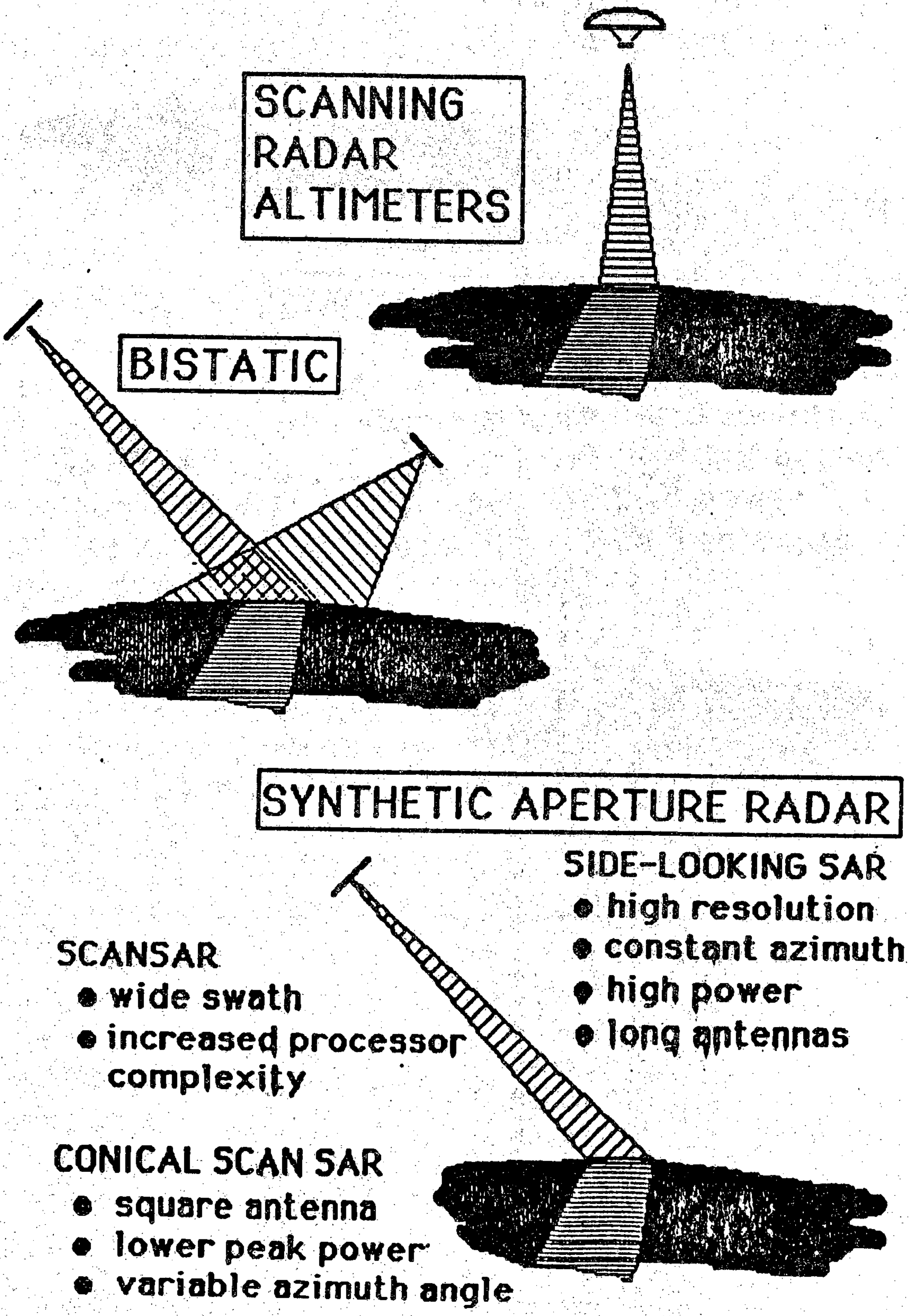
SPATIAL

- active microwave (SAR): 10-25 m
- passive microwave : 100 m - 10 km
- thermal IR : 50 - 100 m
- SWIR : 10 - 25 m
- Visible/Near IR : 10 - 25 m

COVERAGE

- complete coverage swath width determined by revisit interval
- revisit interval interval set by user
- practical for SAR : 50 - 200 km
- narrow swaths OK for research

SPACEBORNE IMAGING RADAR DESIGNS



SCANNING
RADAR
ALTIMETERS

BISTATIC

SYNTHETIC APERTURE RADAR

SIDE-LOOKING SAR

- high resolution
- constant azimuth
- high power
- long antennas

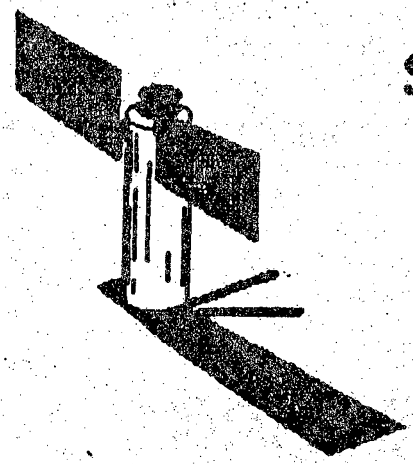
SCANSAR

- wide swath
- increased processor complexity

CONICAL SCAN SAR

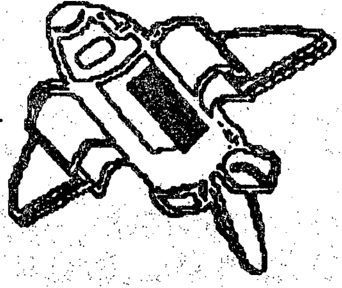
- square antenna
- lower peak power
- variable azimuth angle

SPACEBORNE SAR EVOLUTION



SEASAT

- o June - October, 1978
- o L-band, 20 deg. inc.
- o HH polarized
- o 25 m resolution
- o 100 km swath



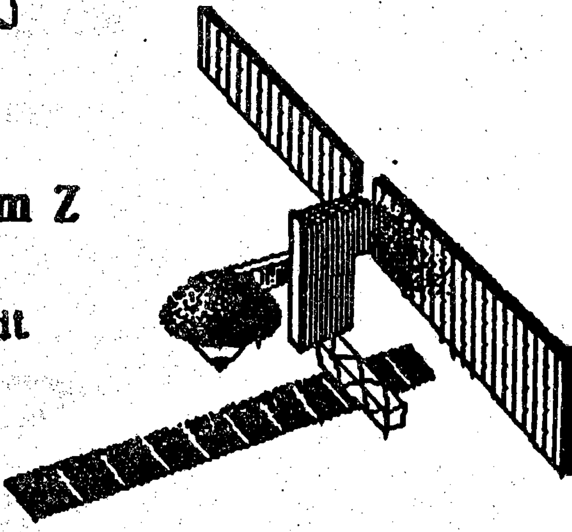
Shuttle Imaging Radar

SIR-A
- o Nov, 1981

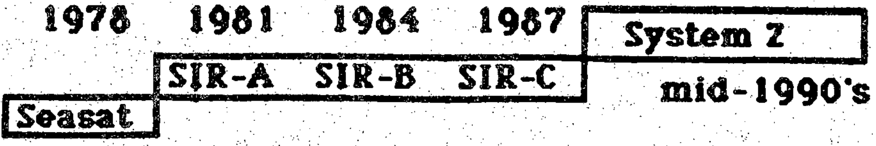
SIR-B
- o Aug, 1984

SIR-C
- o early 1987

Space Station / System Z



- o mid-1990's
- o free-flyer, polar orbit
- o > 5 year life
- o earth observations
- o multi-sensors
- o advanced SAR



1978 1981 1984 1987

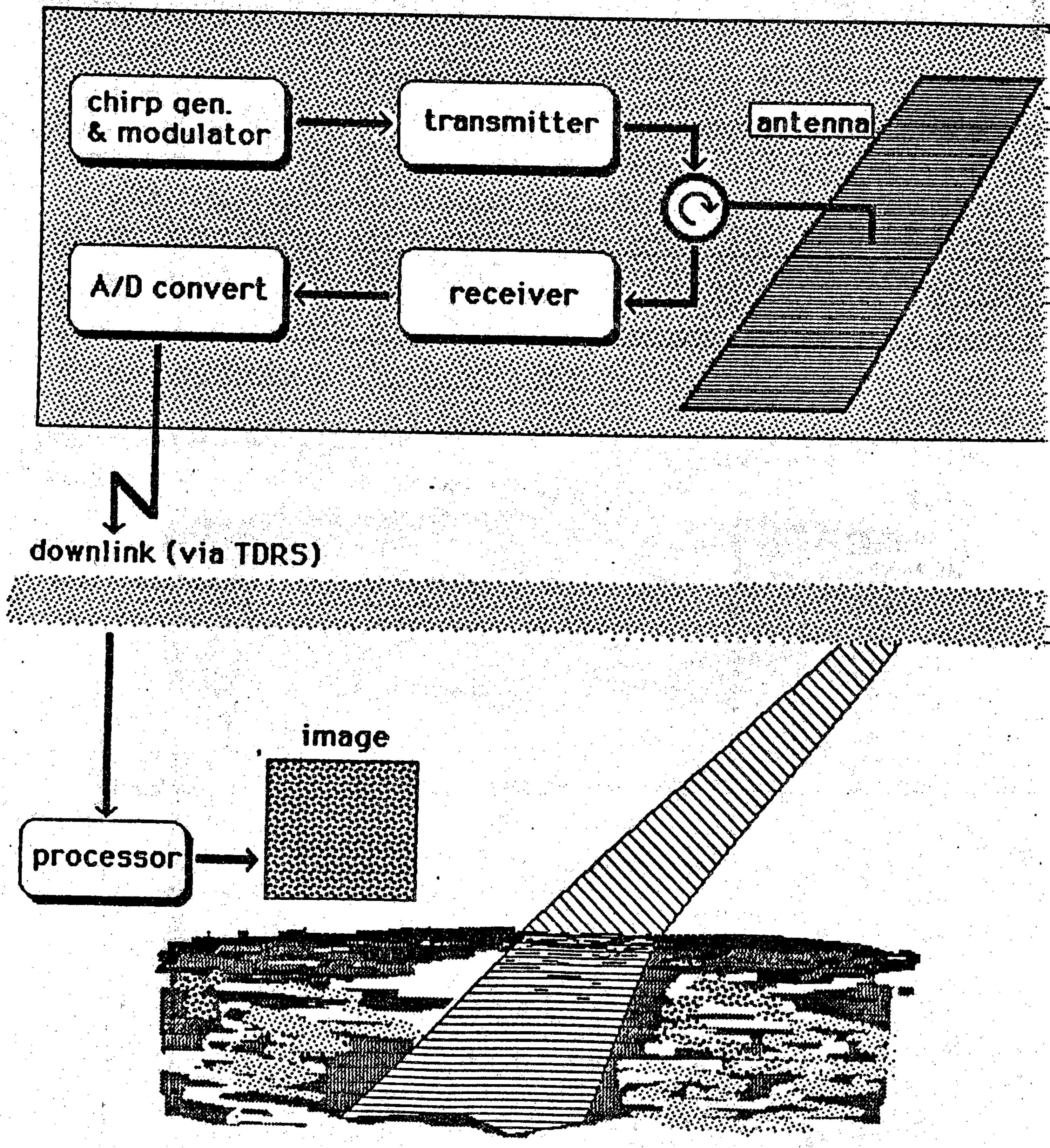
System Z

SIR-A SIR-B SIR-C

mid-1990's

Seasat

SAR BLOCK DIAGRAM



SPACEBORNE IMAGING SENSOR TECHNOLOGY DRIVERS

SPACECRAFT RESOURCES

- ☐ PRIME POWER
- ☐ HEAT TRANSFER
- ☐ SENSOR DEPLOYMENT

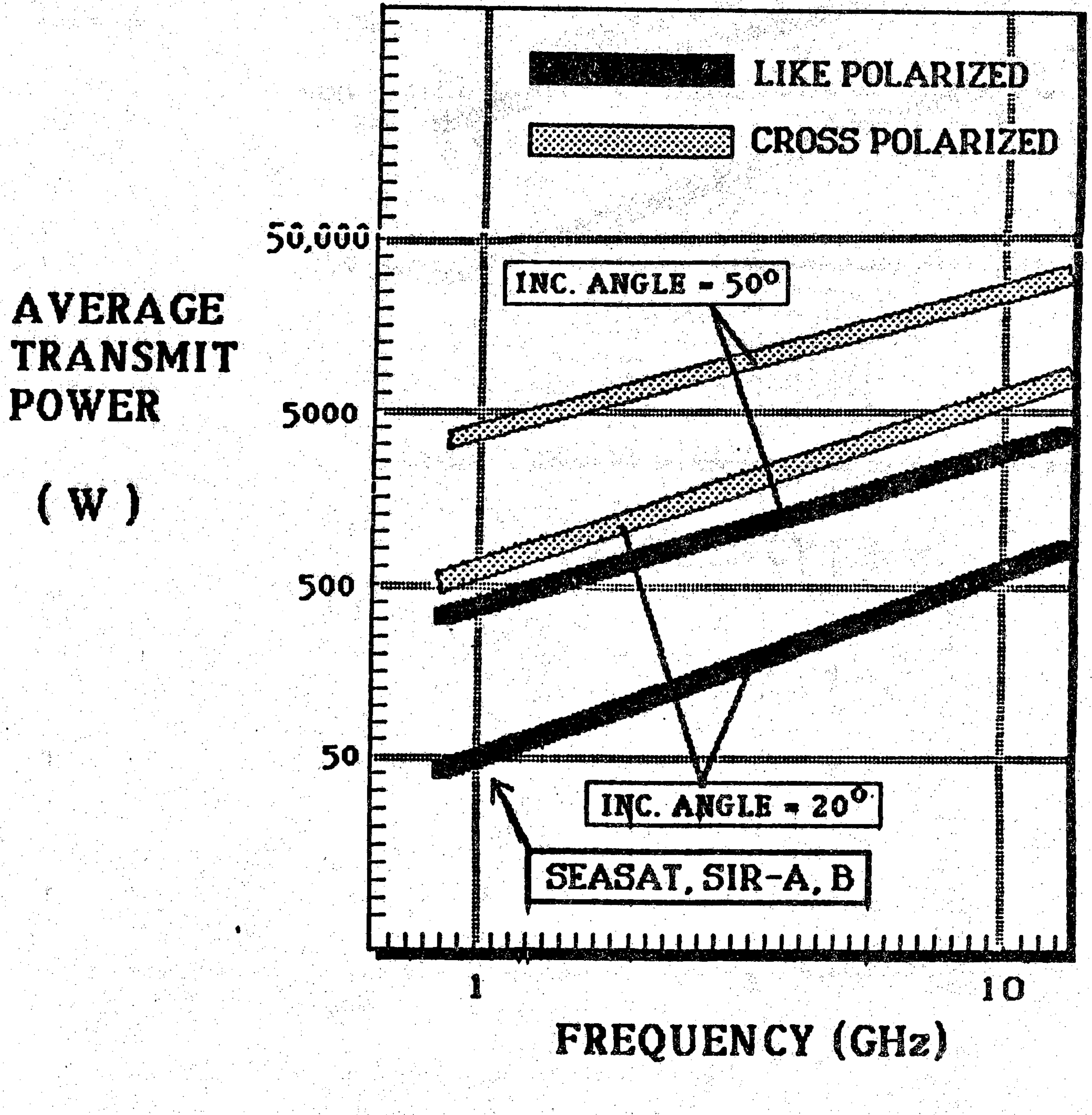
DATA

- ☐ A/D CONVERSION
- ☐ DATA RATES
- ☐ DATA STORAGE
- ☐ DATA PROCESSING

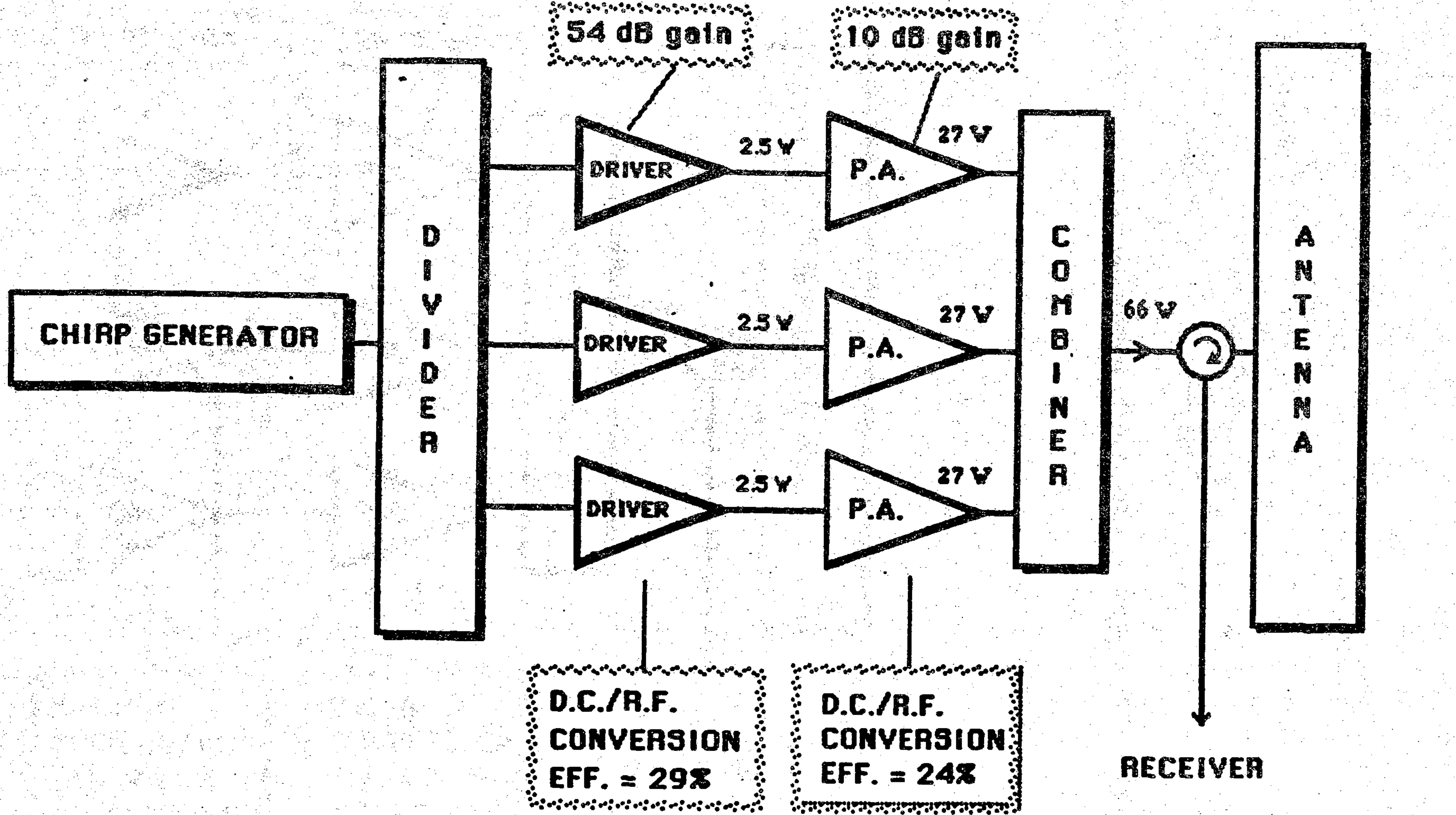
SENSOR

- ☐ SENSITIVITY
- ☐ CALIBRATION
- ☐ PARAMETER FLEXIBILITY

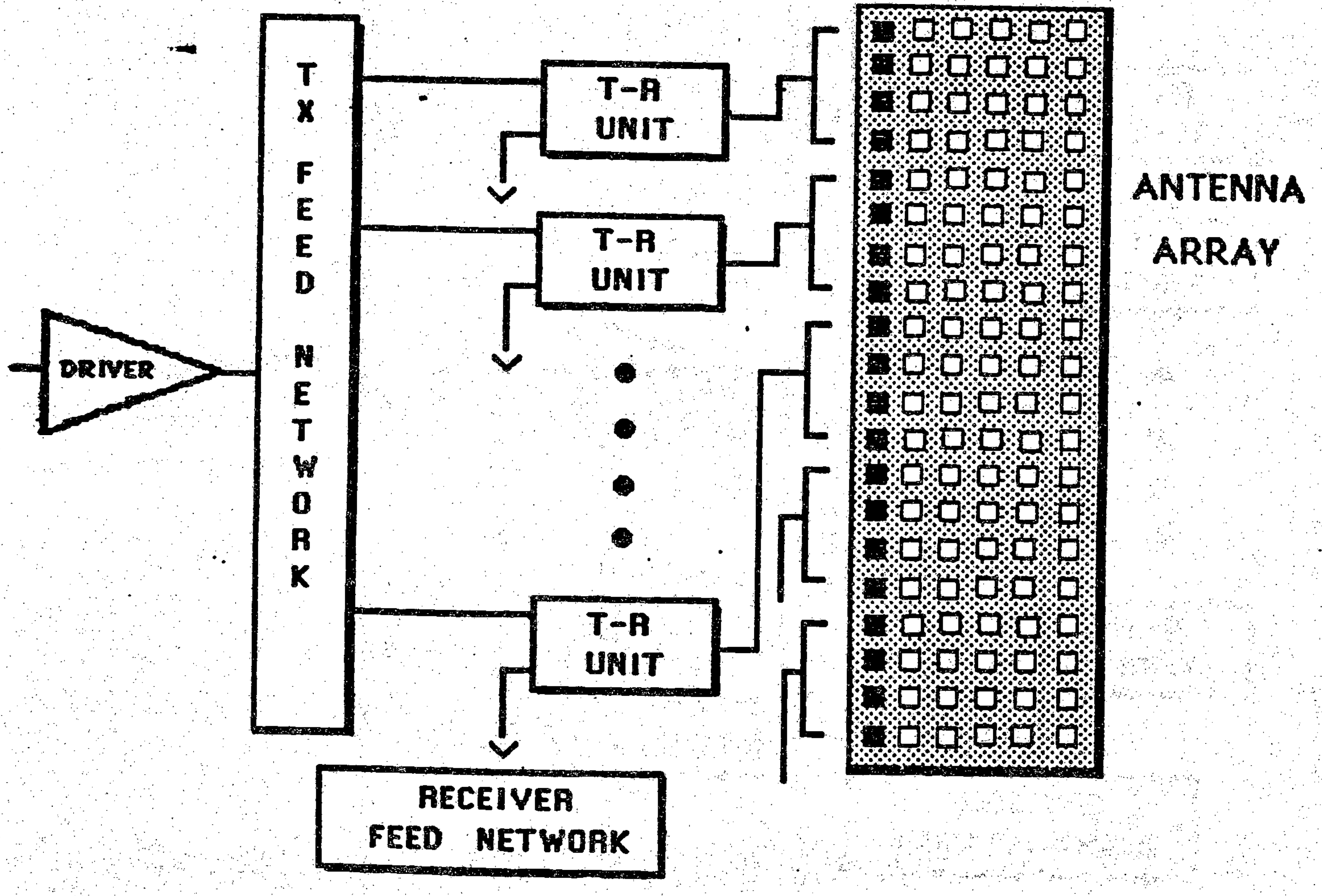
TRANSMIT POWER VS. FREQUENCY FOR AV. TERRAIN



PARALLELED
SOLID-STATE AMPLIFIERS (SEASAT, SIR-A, B)



DISTRIBUTED SAR ARCHITECTURE



DISCRETE VS. MONOLITHIC PA MODULES

DISCRETE MODULES

FREQUENCY	POWER LEVEL
UHF	350 W
L-BAND	50 W
S-BAND	5 W
X-BAND	.5 W

Si-Bipolar : 5 W @ 4 GHz
GaAs FET : 0.5 W @ 4 GHz

MONOLITHIC MODULES

FREQUENCY	POWER LEVEL
L-BAND (Si on sapphire)	0.5 W
S-BAND (Si on sapphire)	120 mW
S-BAND (GaAs)	> 1 W
X-BAND (GaAs)	600 mW

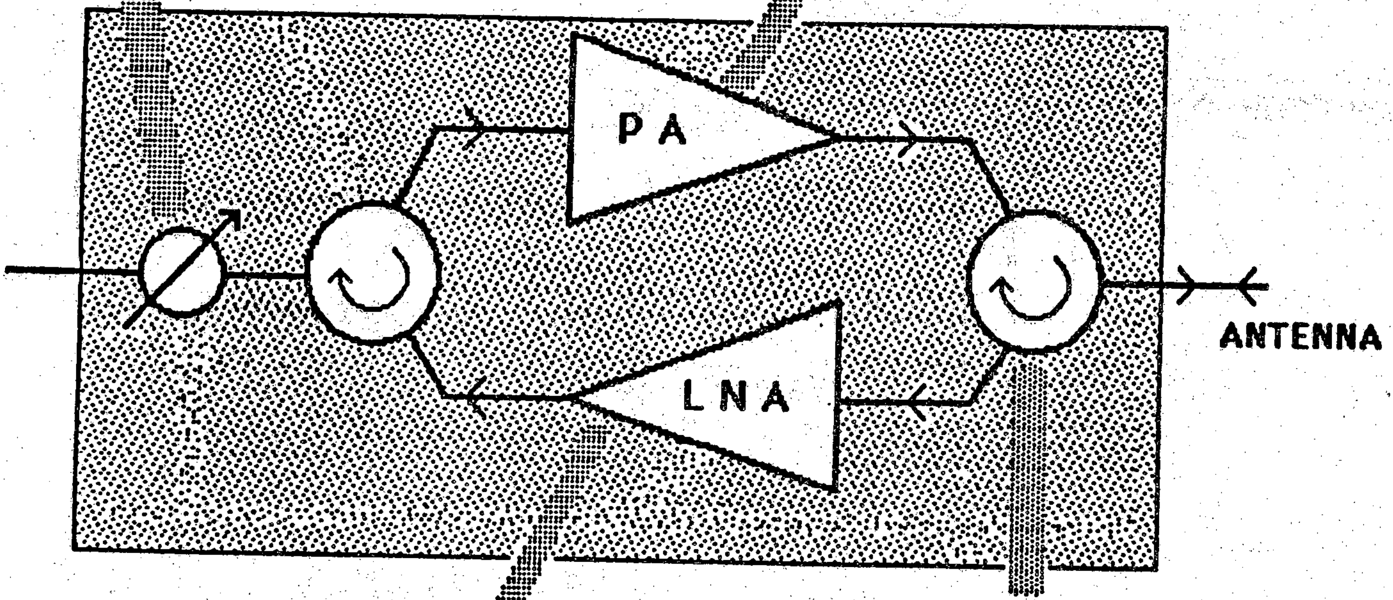
CURRENT TECHNOLOGY: X-BAND MONOLITHIC GaAs T/R MODULES

PASSIVE PHASE SHIFTERS

NO. BITS	INS. LOSS
4	5 dB

POWER AMPLIFIER

NO. STAGES	POWER OUT	GAIN	BANDWIDTH
2	660 mW	13.7 dB	10 %
2	1600 mW	9 dB	15 %
3	700 mW	20 dB	
4	700 mW	28 dB	



T/R SWITCHES

INS. LOSS	ISOLATION	POWER HANDLING
0.5 dB	> 30 dB	1 W
> 2 dB	> 25 dB	10 W

LOW-NOISE AMPLIFIERS

NO. STAGES	NOISE FIG.	GAIN	BANDWIDTH
1	3.5 dB	9 dB	10 %
2	4.0 dB	17 dB	10 %
3	4.0 dB	27 dB	10 %
3	3.0 dB	27 dB	

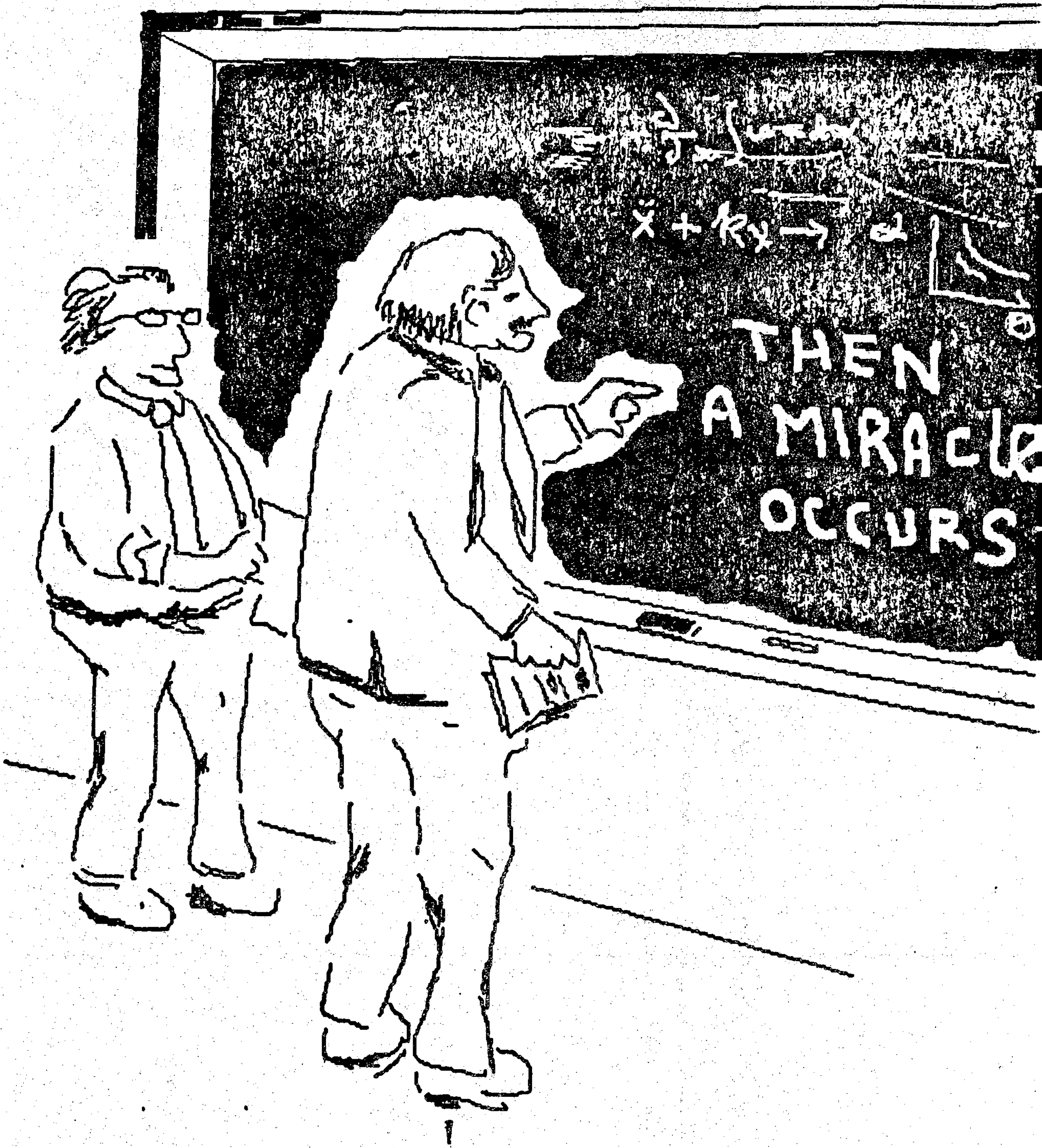
SUMMARY OF SAR TRANSMITTER DESIGN CHALLENGES

PERFORMANCE REQUIREMENTS

- TRANSMIT POWER (LIKE POL , 20°)
  - 50 W av., 1 kW peak at L-Band
  - 500 W av., 10 kW peak at X-Band
- TRANSMIT POWER (LIKE POL , 50°)
  - 450 W av., 9 kW peak at L-Band
  - 4 kW av., 80 kW peak at X-band
- TRANSMIT POWER (CROSS POL, 50°)
  - 4.5 kW av., 90 kW peak at L-band
  - 45 kW av., 900 kW peak at X-band
  - impractical with this type of SAR!
- SPACE QUALIFIED
- 3 - 5 YEAR LIFETIME

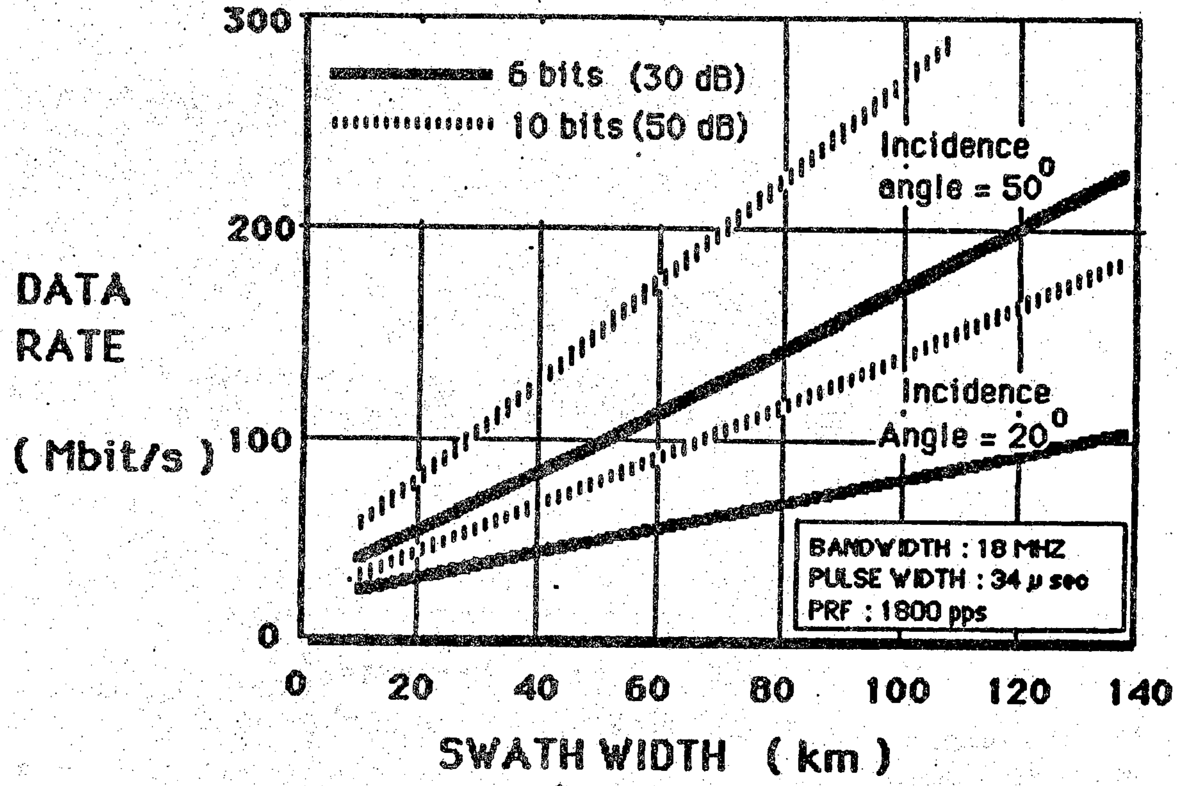
CANDIDATE TRANSMITTER DESIGNS

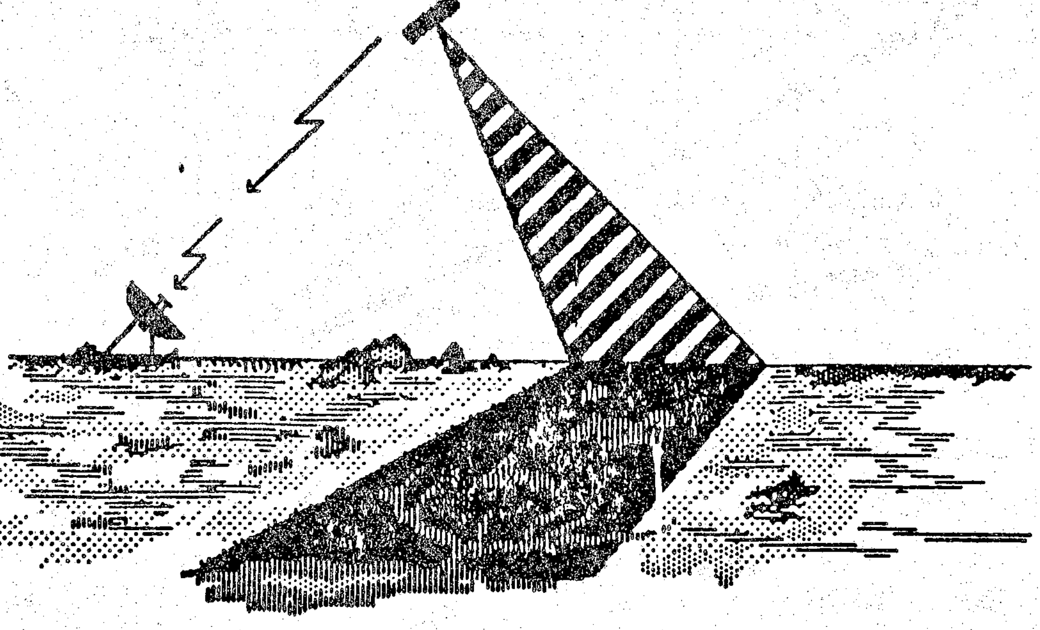
- L-Band, C-Band
  - PARALLELED SOLID-STATE PA, ala SEASAT
  - DISTRIBUTED GaAs FET HYBRID OR MONOLITHIC
- X-Band
  - DISTRIBUTED GaAs FET HYBRID OR MONOLITHIC
    - > 10,000 modules may be required
    - graceful failure
    - major development effort required
  - HIGH-POWER PULSED TWT AMPLIFIER
    - none have been space qualified
    - weight > 40 kg (aircraft version)
    - high-voltage power supply required



" I think you should be more explicit here in step two."

DATA RATE
VS. SAR SWATH WIDTH





ANALOG TO DIGITAL CONVERTER TECHNOLOGY

CURRENT ADC TECHNOLOGY FOR SIR-B

- 6 bits
- 100 MHz clock
- operates at 47 Mbit/sec

REPRESENTATIVE STATE-OF-THE-ART ADC

- TRW TDC1029 ADC
  - monolithic
  - 6 bits
  - 100 MSPS
  - 50 MHz input bandwidth
  - no sample and hold circuit needed
  - 63 comparators

CURRENT ADC RESEARCH TRENDS

- Smaller gate technology
  - triple-diffused bipolar transistors
- Superconducting IC technology
  - Superconducting Quantum Interference Devices (SQUID) ideal for ADC comparators
  - 6-bit SQUID ADC comparators tested at 4 GHz clock rate
  - 8-bit SQUID ADC being developed
  - SQUID technology not easy to implement for space radars

MASS STORAGE MEDIA

MISSION APPLICATIONS

- Shuttle imaging radar missions
- Space platform SAR missions

CURRENT TECHNOLOGY:

MAGNETIC TAPE RECORDERS

- Odetics 50 Mbit/sec recorder, space-qualified
- ESA 37 Mbit/sec recorder

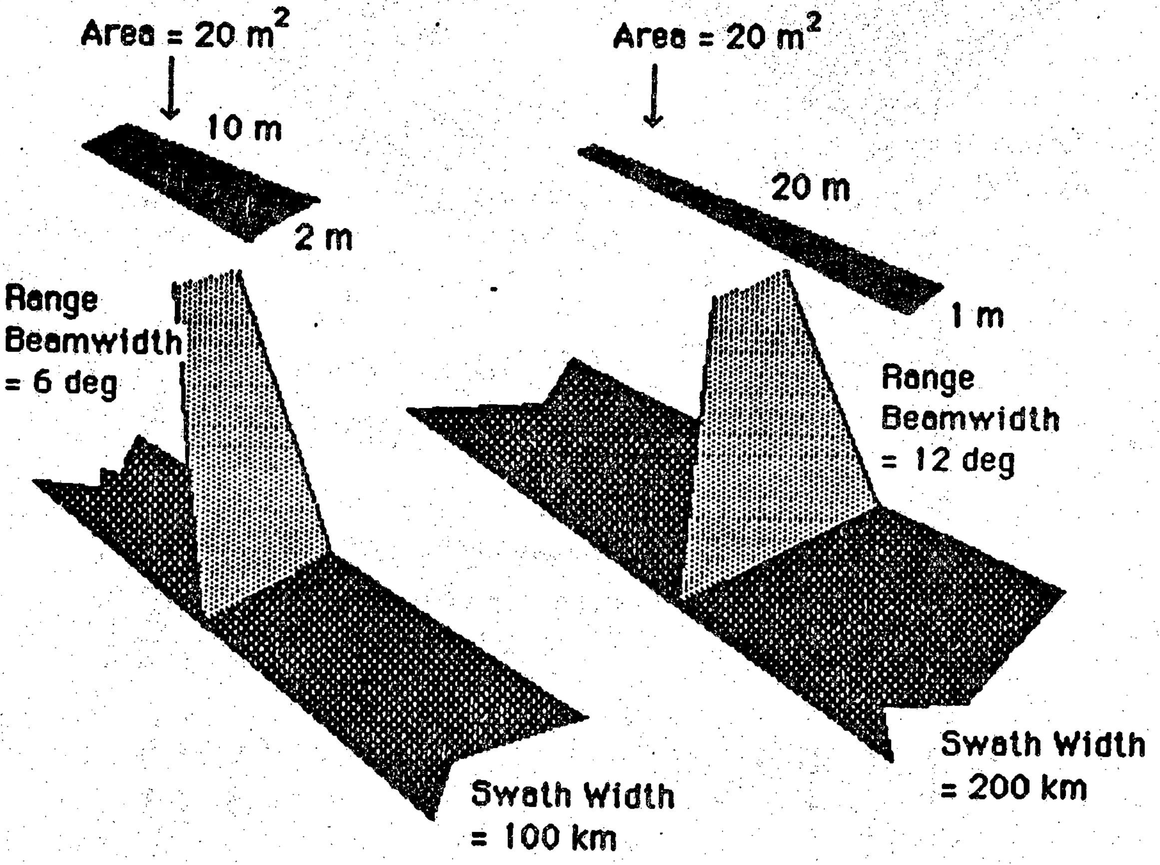
OPTICAL DISK MEMORY SYSTEMS

- Nonerasable read only or read/write platters
- Storage Technology Corp. Model 7600 Optical Storage System:
  - stores 4 Gigabytes on one side of 14" nonerasable disk
  - equal to 40 reels of magnetic tape
  - 3 Mbytes/sec transfer rate

FUTURE TECHNOLOGY:

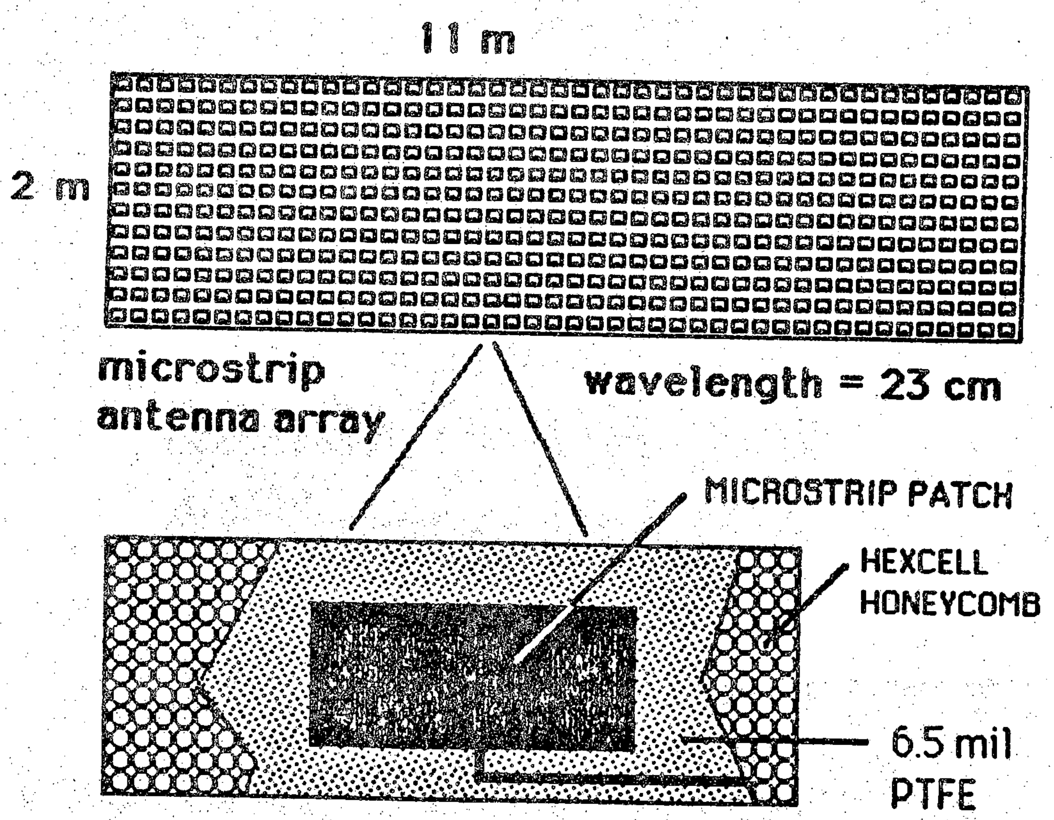
- LASER DISK WURLITZERS?
- BIOCHIP TECHNOLOGY?

SWATH WIDTH RELATION TO SAR ANTENNA SIZE

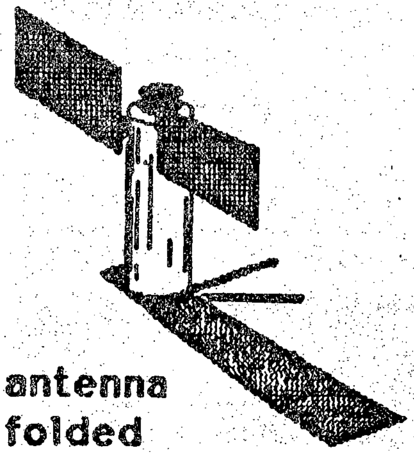


- FOR A GIVEN AMBIGUITY (ALIAS) LEVEL, THE ANTENNA AREA IS CONSTANT
- CUTTING THE ANTENNA WIDTH IN HALF DOUBLES THE SWATH WIDTH (IF NOT DATA RATE LIMITED)
- BUT ANTENNA MUST THEN BE MADE TWICE AS LONG !

SEASAT, SIR-A,B ANTENNA DESIGN

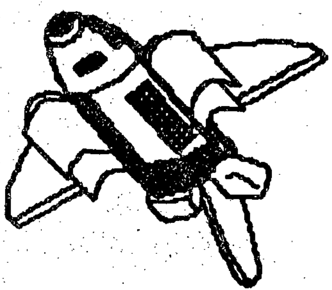


FREE FLYER



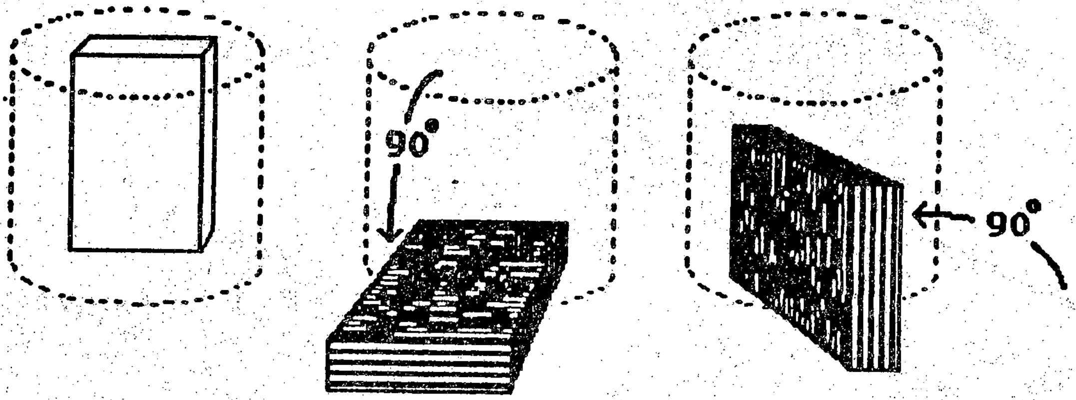
antenna
folded
before launch

SHUTTLE

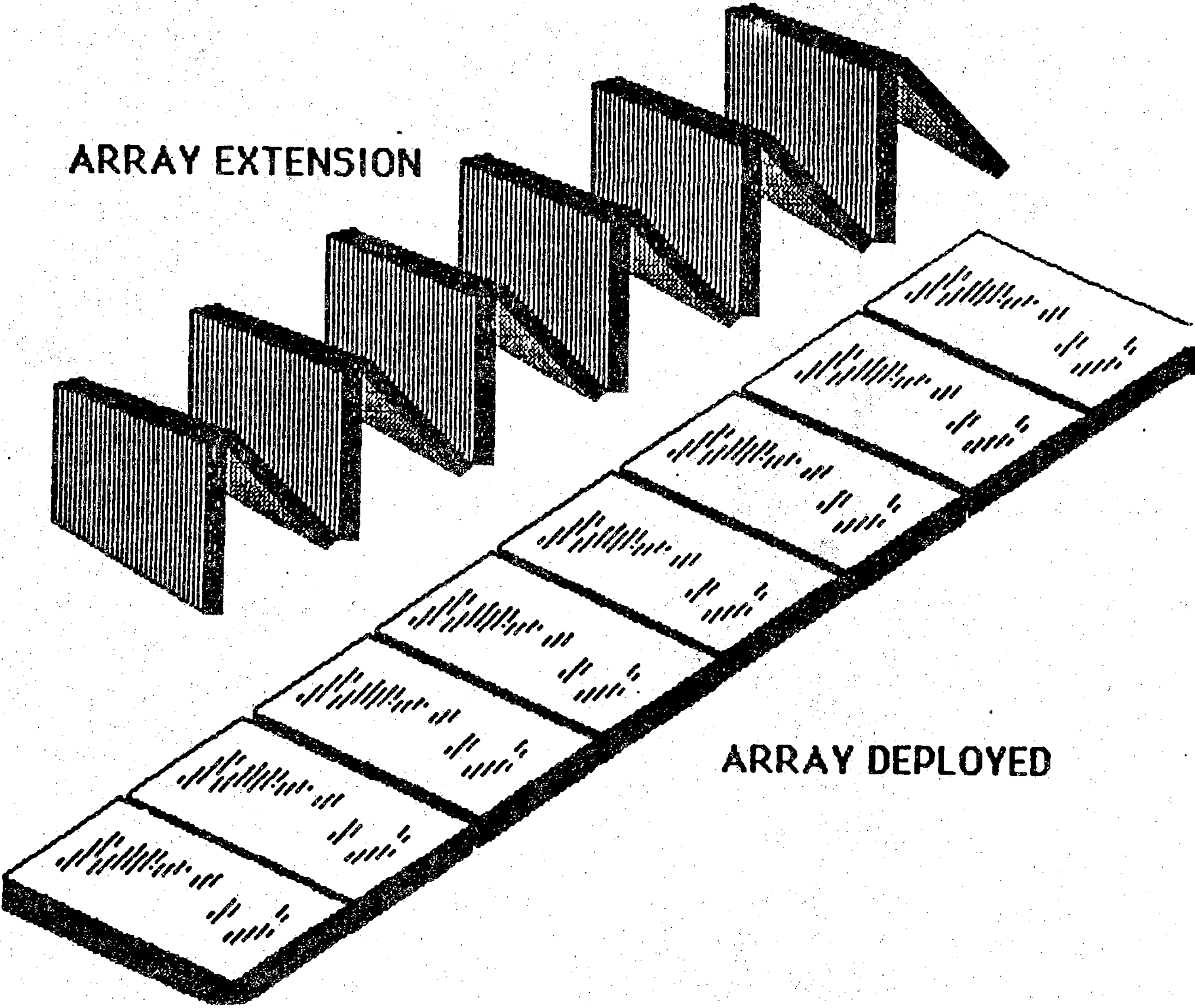


antenna
folded during
launch & landing

SAR ANTENNA DEPLOYMENT
(FREE - FLYER)

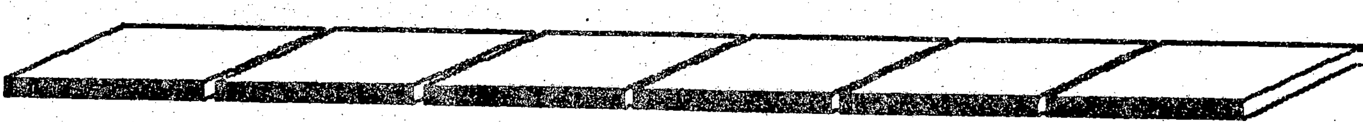


STOWED SECOND STAGE DEPLOYMENT

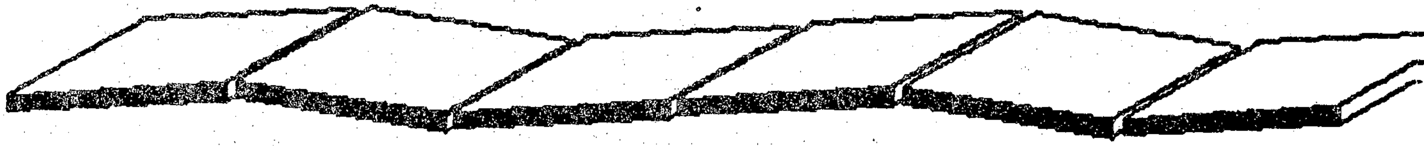


SAR ANTENNA FLATNESS

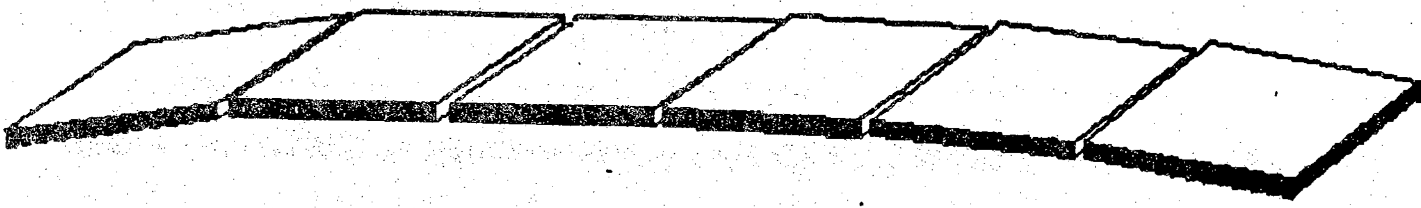
FLAT



UNFOLDING ERROR



PARABOLIC BOW



EFFECTS OF OUT-OF-FLATNESS

UNFOLDING ERROR

- beam tilt (geometric fidelity)
- asymmetric sidelobes

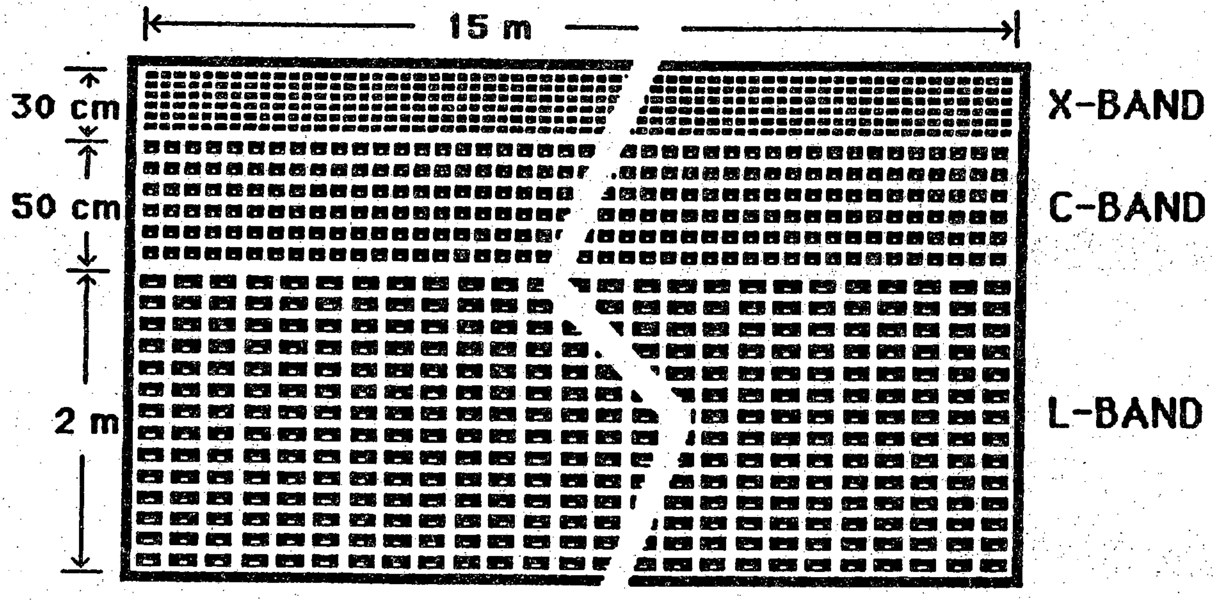
PARABOLIC BOW

- gain reduction (loss of calibration)
- higher sidelobes (higher ambiguities)

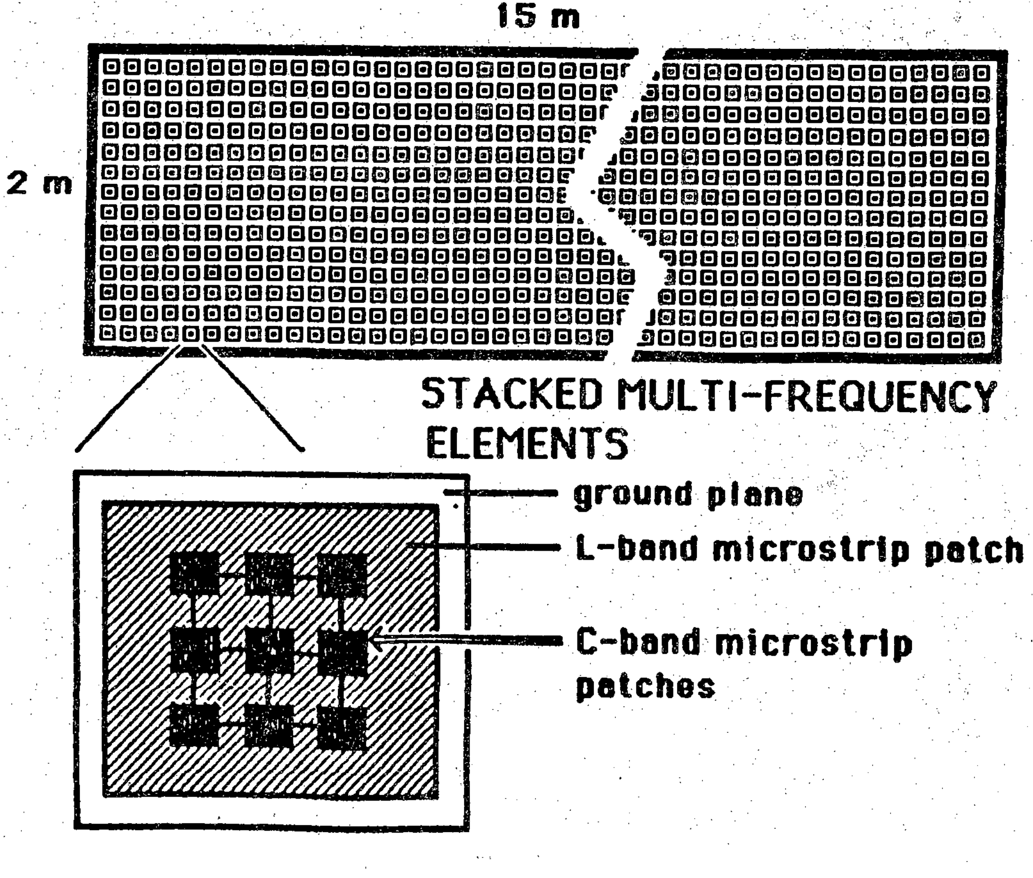
TWIST

- beam tilt
- gain reduction
- higher sidelobes

MULTI-FREQUENCY SAR ANTENNA ARRAYS

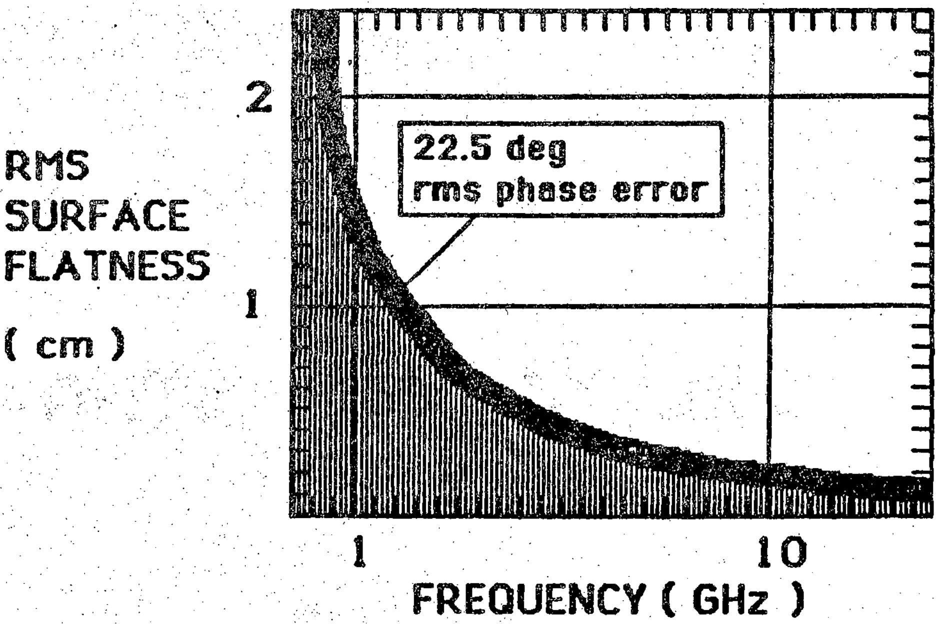


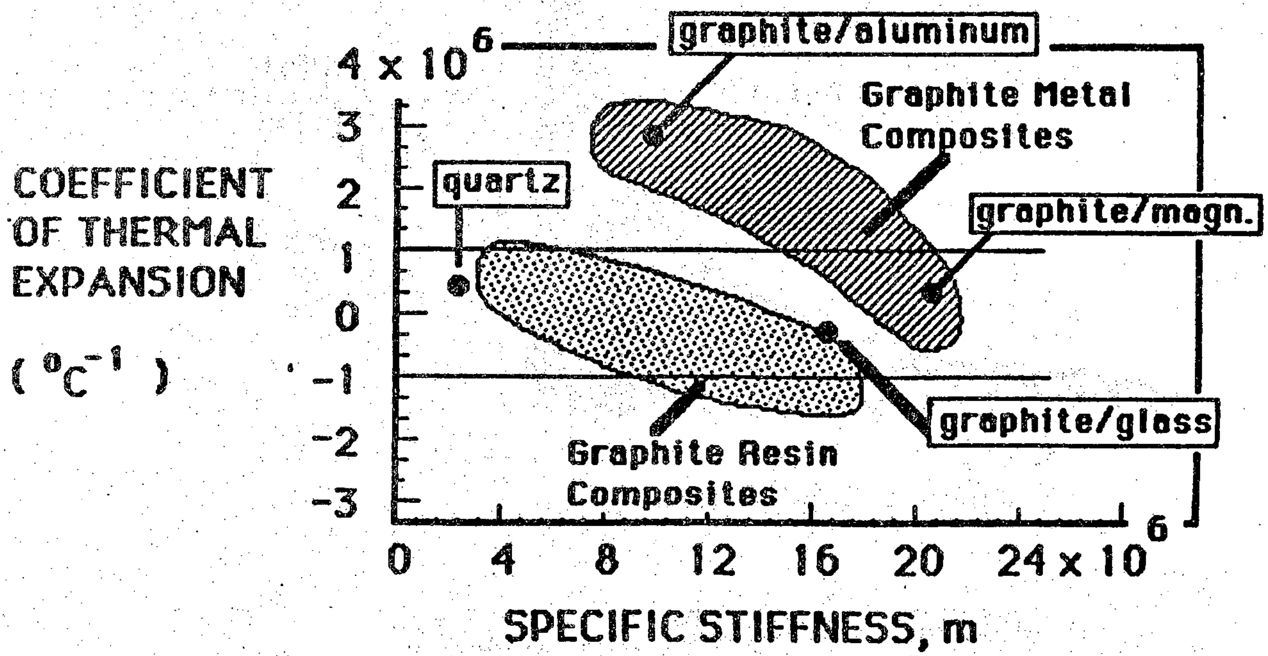
SIDE-BY-SIDE ARRAY



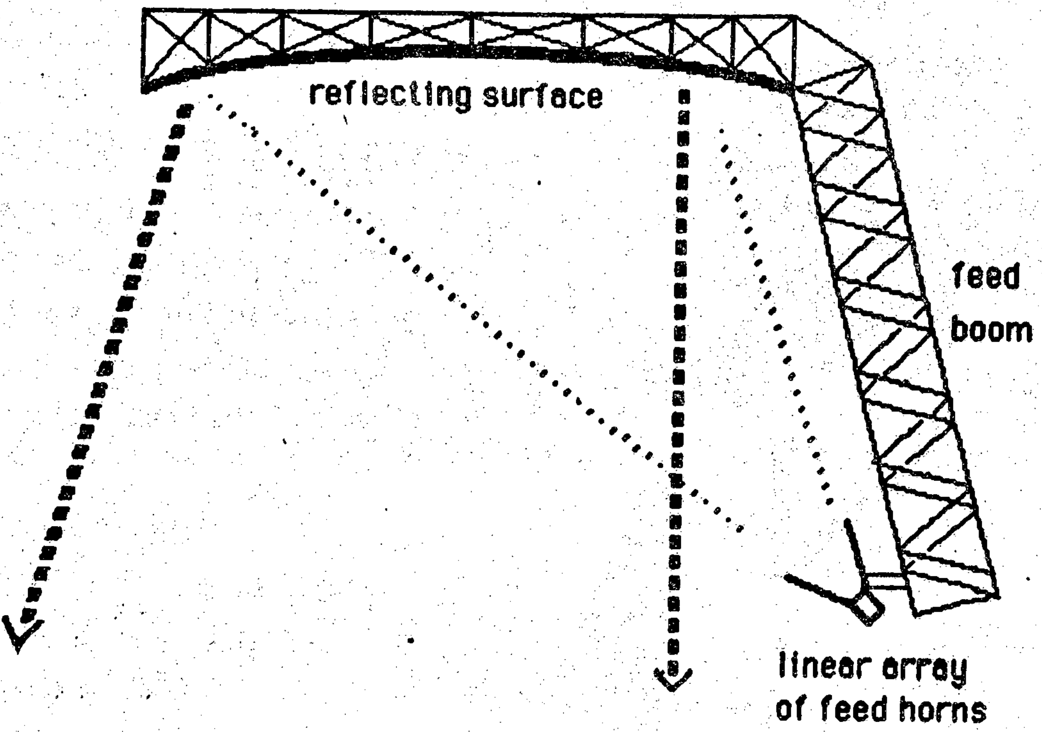
STACKED MULTI-FREQUENCY ELEMENTS

ANTENNA FLATNESS TOLERANCE





CYLINDRICAL PARABOLOID SAR ANTENNA

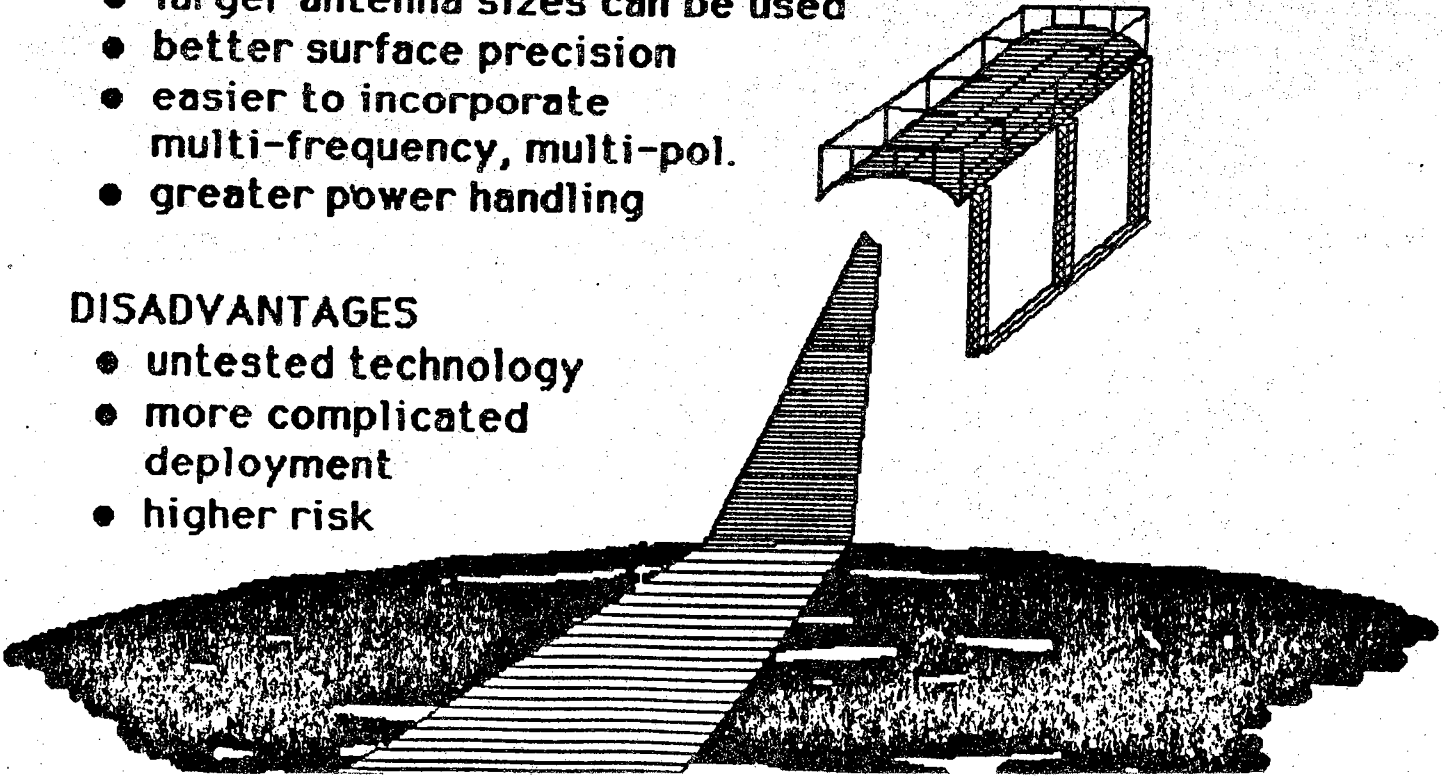


ADVANTAGES OF REFLECTOR

- larger antenna sizes can be used
- better surface precision
- easier to incorporate multi-frequency, multi-pol.
- greater power handling

DISADVANTAGES

- untested technology
- more complicated deployment
- higher risk



SAR ANTENNA TECHNOLOGY CHALLENGES

ANTENNA DESIGN

- multi-frequency arrays
- integration with MMIC
- deployable reflector designs

ARRAY DESIGNS

- multi-frequency elements
- distributed SAR
- electronically scanned SAR

CONSTRAINED GEOMETRIES

- folded/deployable
- precision surface : $\lambda/20$

STRUCTURAL DESIGN

- advanced composites
- long space life

summary

SPACEBORNE SAR TECHNOLOGY CHALLENGES

DATA

- VERY HIGH-SPEED , HI-RES A/D CONVERTERS
- ULTRA WIDE-BAND DATA RELAY SATELLITES
- REAL-TIME ON-BOARD IMAGE PROCESSORS

TRANSMITTERS

- HIGH-POWER SPACE-QUALIFIED TRANSMITTERS
- MONOLITHIC T/R MODULES FOR DISTR. SAR

SPACECRAFT RESOURCES

- HIGH-POWER (> 10 kW) PRIME POWER SOURCES
- ADVANCED SPACE MATERIALS (LOW CTE, HIGH STIFFNESS)
- NOVEL DESIGNS FOR LARGE SPACE STRUCTURES

ANTENNAS

- ARRAY & REFLECTOR DESIGNS FOR LARGE SPACEBORNE SAR ANTENNAS
- PRECISION SURFACE TOLERANCE TECHNOLOGY
- MULTI-FREQUENCY ANTENNA DESIGNS
- ELECTRONICALLY BEAM-SCANNED SAR

APPENDIX G: Summary of Remarks of Robert M. Haralick

Remote sensing was originally handled by camera systems with analysis of the spatial patterns being the principal means of information extraction. Later spectral information was added followed by point processing by a computer. This capability influenced sensor development and the users of the technology were forced to talk the same language. The topic to be discussed today is how can the various tasks that a photo interpreter goes through while learning a spatial pattern be automated. What is needed is a multi-level model and physical nature of the environment and an understanding of the interaction between scene, sensor, and analyst. Ancillary data is the basis of the model that we have with maybe no point operators at all.

Can we determine intrinsic surface characteristics from Landsat imagery of mountainous terrain? Solar input, cover types, topography, atomspheric effects, and the sensor are all factors in the point-by-point image scene correlation. We aim to extract haze information, the shadow image, diffuse light information, reflectance information, and topographic information. We explain surface aspect ratios, reflectance characteristics, and the way the surface is illuminated and then recombine the data to explain what the Landsat has seen. Should we refer to goniometric instead of topographic (usable in flat areas with rough objects)?

Using an image from a West Virginia scene the data is destriped using Horn's method. It is April data with green grass but the trees are not yet leafed. Assume a Lambertian reflector illuminated by a point source so that $G(x,y) = r(x,y)I\cos\Theta xy$, where Θxy is the angle between the sun incidence angle the surface normal. Assume no view angle effects. Consider directly lit pixels and shadowed pixels. That is, $G(x,y,b)I(b)\cos Oxy + r(x,y,b)I(b) + H(b)$ and $G(x,y,b)D(b) + H(b)$. The Lambertain and diffuse illumination effects are accounted for with this method.

For haze correction use Switzer, Kowalik, and Lyon technique. Subtract out the haze with appropriate modification of equations. The correction is done in band seven and is not a strong correction. We want to get three images: diffuse light, reflectance, and topographic. There is no topographic information in the shadowed pixels. Now split the image into two clusters with similar properties, material reflectance and topography (not directly possible for tophography). Now form spectral-band ratios for the directly lit pixels. Also assume the same situation for the diffuse light, that is, the ratio of the bands is the same as the ratio of the reflectances and the same will be true for the shadowed pixels. Then cluster on the resulting reflectance data and that will give the material cluster.

Now overlay the shadow/lit data on the material cluster image and do a sub-cluster on the dehazed values. Then decide which cluster is bright and which is dark, a decomposition procedure that assumes no spatial continuity. Only primary shadowing effects are considered. Each pixel belongs to a material cluster, and each material cluster has a bright and a dark subcluster. Now define pixels value in the diffuse image to be the average value of all pixels from the dark sub-cluster. We then obtain a diffuse light image and a reflectance image. After averaging one obtains a topographic image. When images are recombined one obtains the original image.

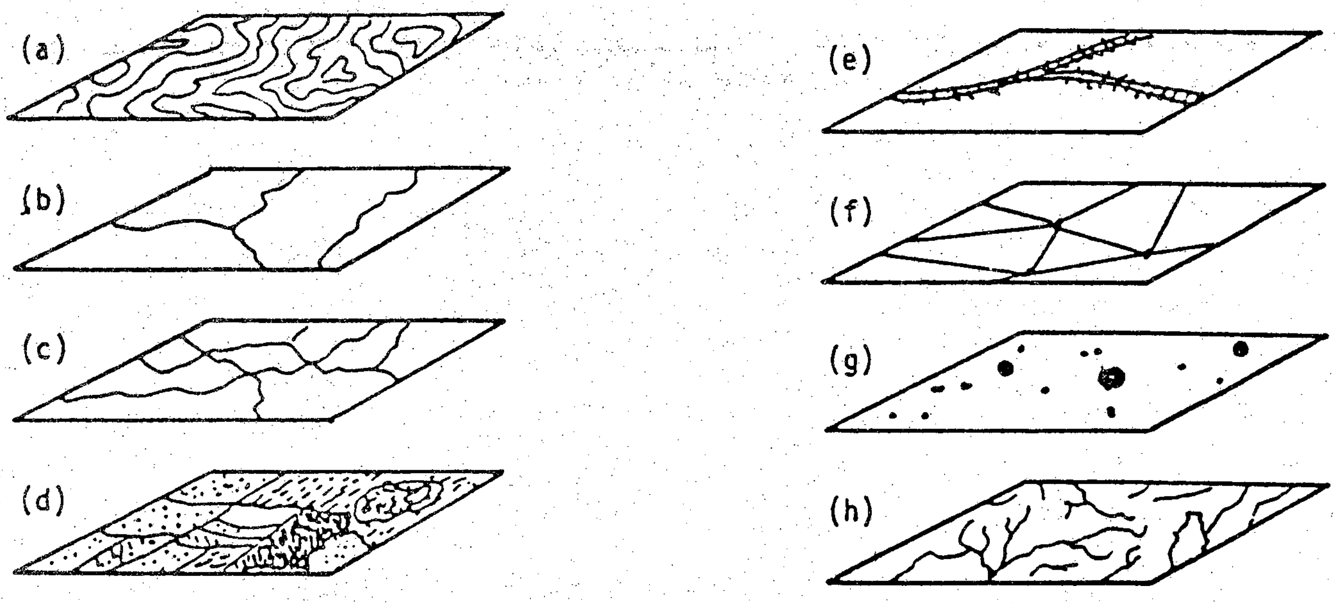
Working with the binary shadow image and the connected components image we can identify ridges (bright to dark), valleys (dark to light) and classify into valleys and ridges. The neighboring valleys are lower than the ridges and the river is lowest of all. The resulting elevations compared favorably to the DMA tapes of the area after smoothing. The first order structure was explained by the model but the procedure takes a great deal of computer time but the thinking process of the interpreter was, to a degree, automated.

See: S. Wang, D. B. Elliott, J. Campbell, R. W. Erich, and R. M. Haralick, ''Spatial Reasoning in Remotely Sensed Data," IEEE Trans. Geoscience and Remote Sensing, Vol. GE-21, pp. 94-101, January 1983.

APPENDIX H: Freeman Presentation

MAP DATA PROCESSING AND THE NAME PLACEMENT PROBLEM

H. FREEMAN
RENSSELAER POLYTECHNIC INSTITUTE
TROY, NEW YORK



MAP DATA IN FORM OF DISJOINT OVERLAYS

(A) ELEVATION CONTOURS
(B) POLITICAL SUBDIVISIONS
(C) HIGHWAY NET
(D) LAND USAGE
(E) RAILROAD NET
(F) GEODETIC CONTROL DATA
(G) CITIES AND TOWNS
(H) DRAINAGE LINES

CARTOGRAPHIC DATA BASE TASKS:

- EDITING AND UPDATING
- REMOTE ACCESS
- TRANSFORMATION AND ANALYSIS
- FORMATTING AND GENERATION OF "HARD-COPY" MAP

PROBLEM AREAS:

- SPATIAL DATA STRUCTURES
- EFFICIENT PROCESSING ALGORITHMS
- GENERALIZATION
- ANNOTATION (NAME PLACEMENT) ✓

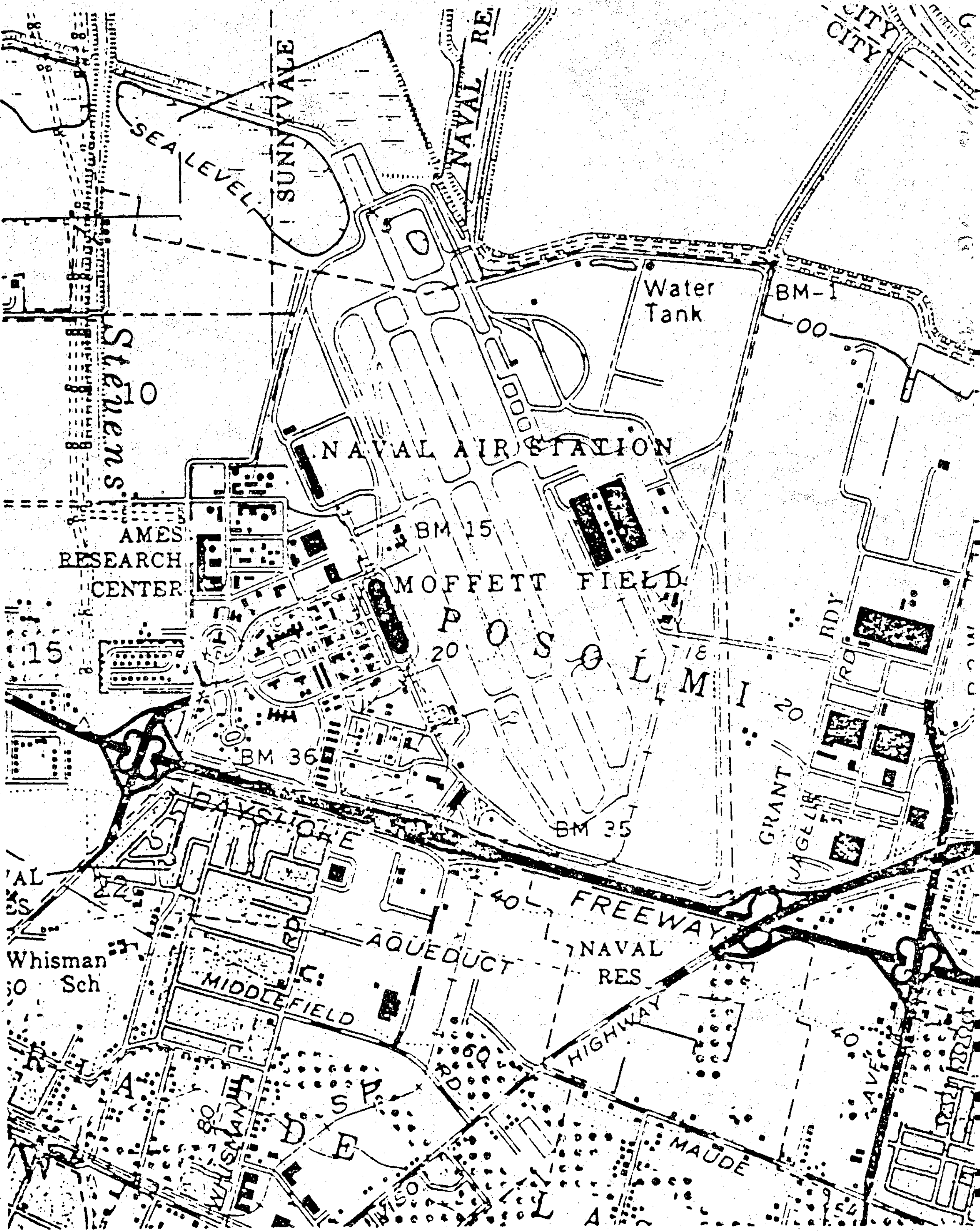
AUTONAP - A KNOWLEDGE-BASED SYSTEM FOR AUTOMATIC MAP NAME PLACEMENT

KNOWLEDGE-BASED SYSTEM

- KNOWLEDGE BASE
- INFERENCE MECHANISM
- PROBLEM DATA

ANNOTATION (NAME PLACEMENT) REQUIRED FOR:

- AREA FEATURES
- POINT FEATURES
- LINE FEATURES


CITY
SEA LEVEL
SUNNYVALE
NAVAL RE
Water Tank
BM-1
00
Stevens
10
NAVAL AIR STATION
AMES RESEARCH CENTER
BM 15
MOFFETT FIELD
POSOLMI
15
20
18
RDY
RD
20
BM 36
BAYSHORE
BM 35
GRANT
JAGELS
AL
ES
40
FREEWAY
AQUEDUCT
NAVAL RES
RD
Whisman Sch
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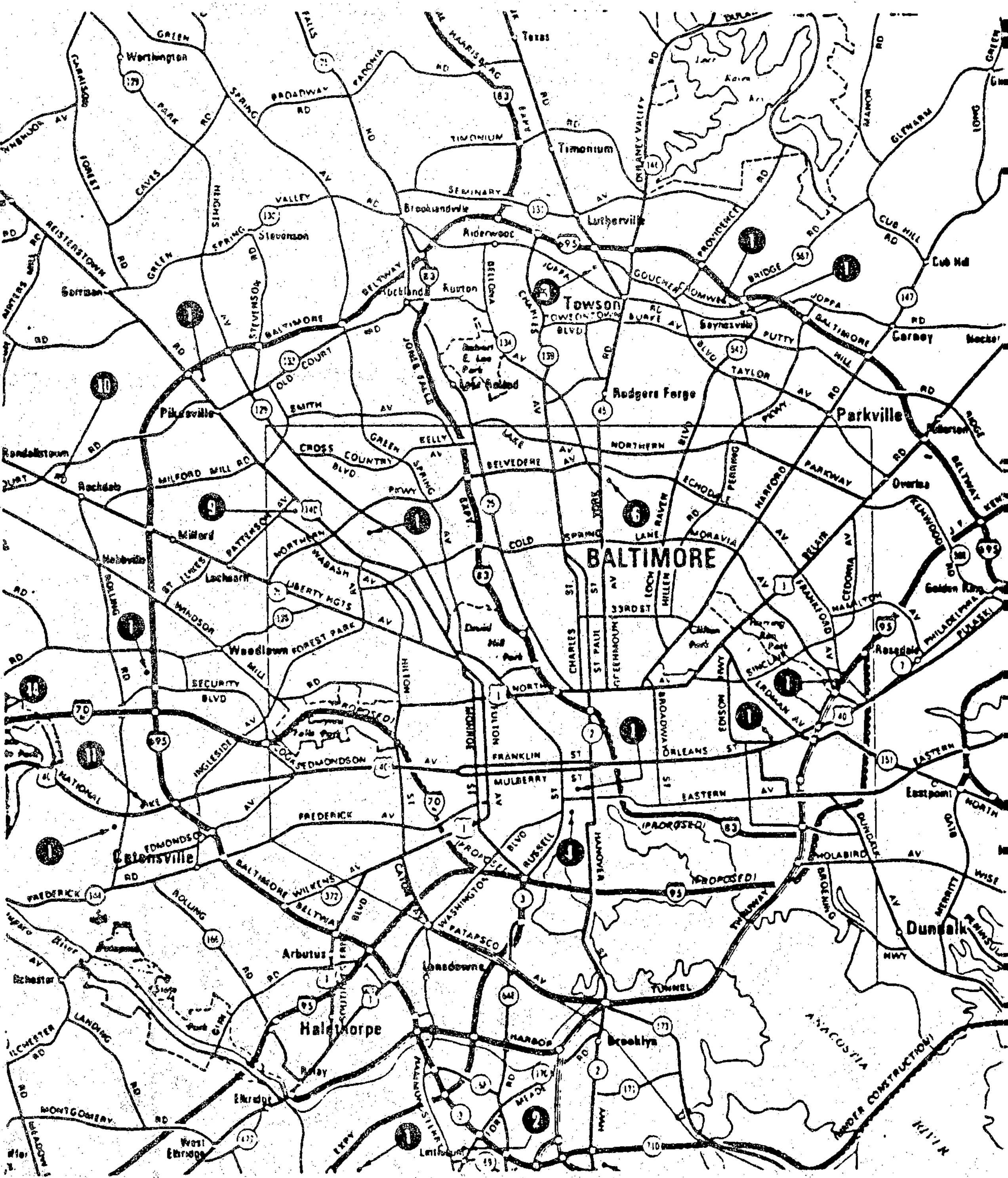
MIDDLEFIELD
HIGHWAY
60
40
RD
80
WHISMAN
AVE
MAUDE
DE
LA
150



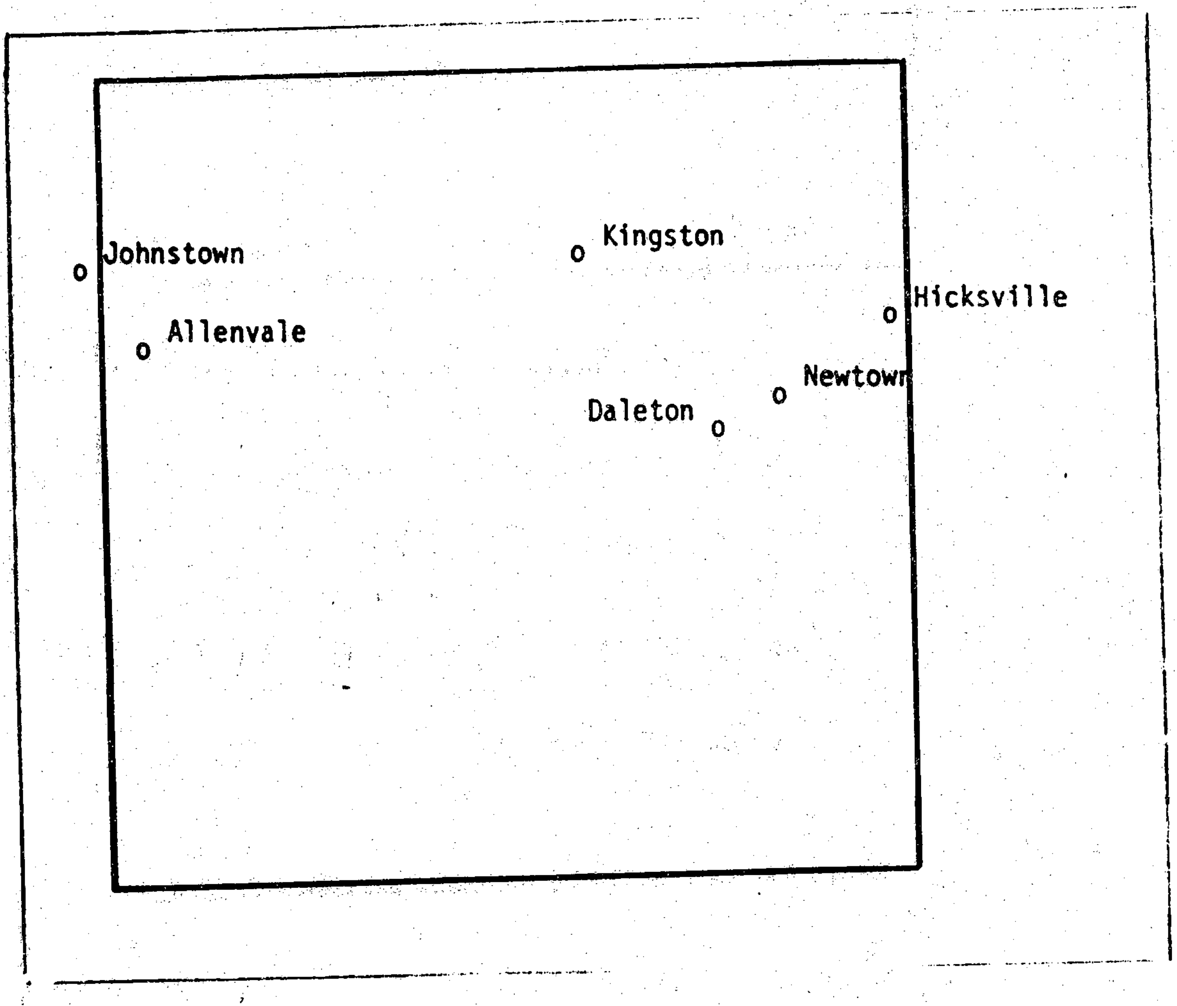
SAMPLE MAP, SHOWING POINT, LINE, AND AREA FEATURE NAMES

H-11


DEPARTMENT OF THE INTERIOR
ROOSEVELT NATIONAL FOREST
ROCKY MOUNTAIN NATIONAL PARK
SCALE 1:24 000
CONTOUR INTERVAL 40 FEET
FALL RIVER PASS, COLO.

OBJECTIVES

- UNAMBIGUOUS ASSOCIATION OF NAME WITH FEATURE
- NO OVERLAP AMONG NAMES
- NO OVERLAP OF NAMES WITH POINT FEATURES
- CONFORMANCE WITH CARTOGRAPHIC CONVENTIONS
- ACHIEVEMENT OF AESTHETIC APPEARANCE


Johnstown
Kingston
Hicksville
Allenvale
Newtown
Daleton

ORDER OF NAME PLACEMENT

--- BASED ON RELATIVE DEGREES OF FREEDOM:

FIRST: - - - - AREA FEATURE NAMES

SECOND: - - - POINT FEATURE NAMES

THIRD: - - - - LINE FEATURE NAMES

GENERAL PRINCIPLES OF NAME PLACEMENT *

1. NAMES SHOULD BE EASILY READABLE AND LOCATABLE.

2. THERE SHOULD BE AN EASILY RECOGNIZABLE ASSOCIATION BETWEEN A NAME AND THE MAP FEATURE TO WHICH IT REFERS.

3. COVERING, OVERLAPPING, AND CONCEALMENT SHOULD BE AVOIDED.

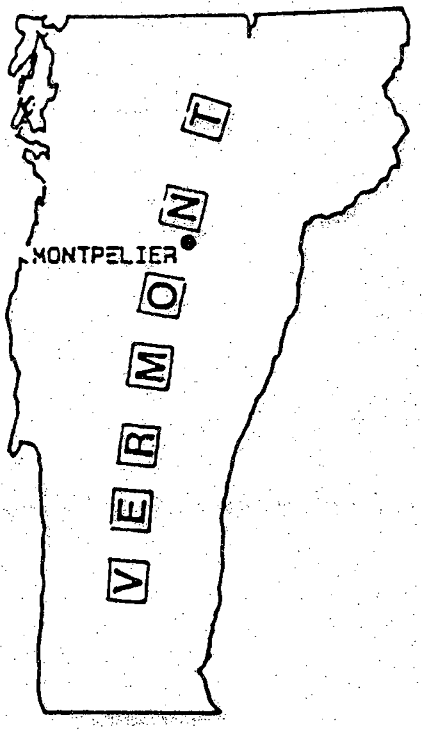
4. NAMES SHOULD ASSIST IN REVEALING SPATIAL RELATIONSHIPS, TERRITORIAL EXTENT, CONNECTION, IMPORTANCE, AND DIFFERENTIATION OF OBJECTS.

5. TYPE ARRANGEMENT SHOULD REFLECT THE CLASSIFICATION AND HIERARCHY OF OBJECTS IN A MAP.

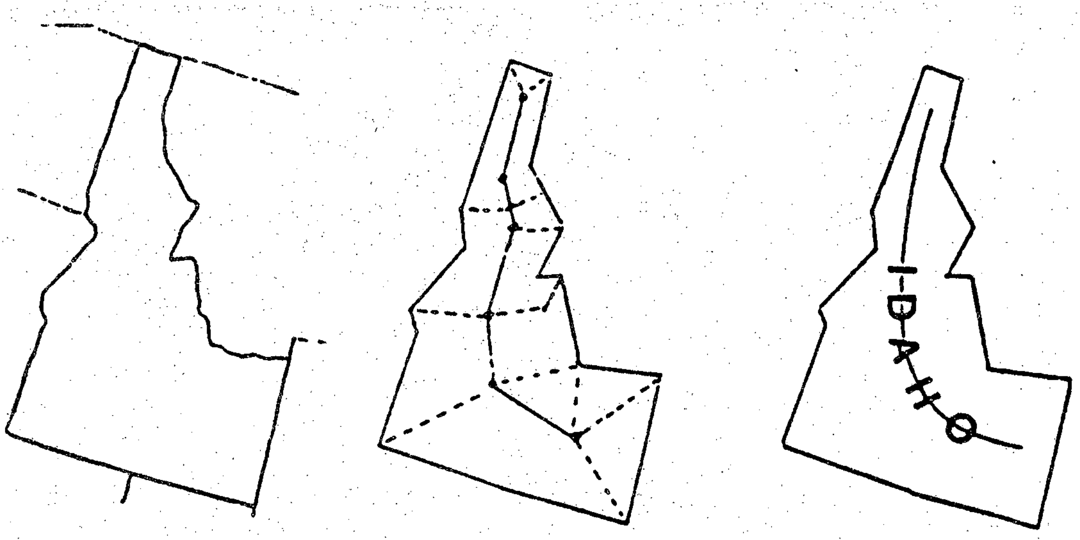
6. NAMES SHOULD NOT BE EVENLY DISPERSED NOR BE DENSELY CLUSTERED.

---

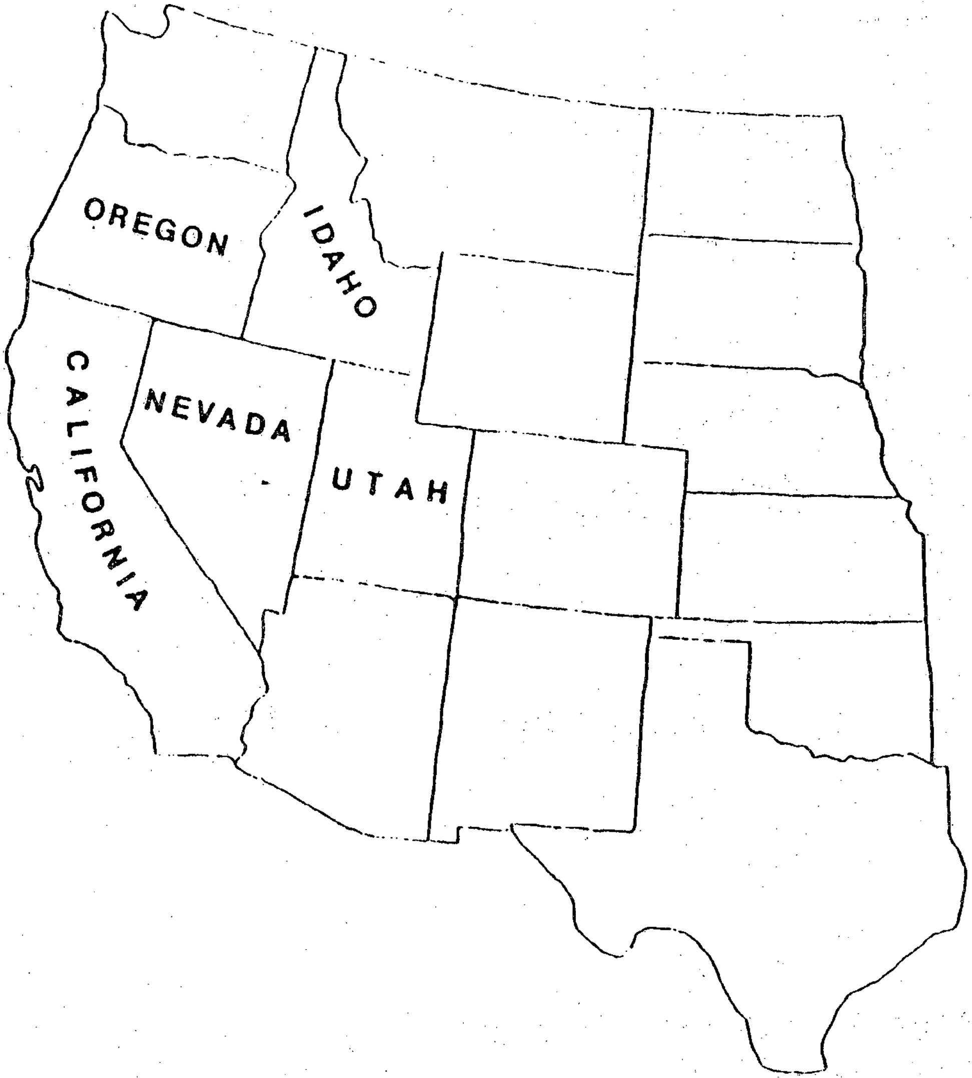
*IMHOF, E., "POSITIONING NAMES ON MAPS," THE AMERICAN CARTOGRAPHER, VOL. 2, NO. 2, 1975, PP. 128-144



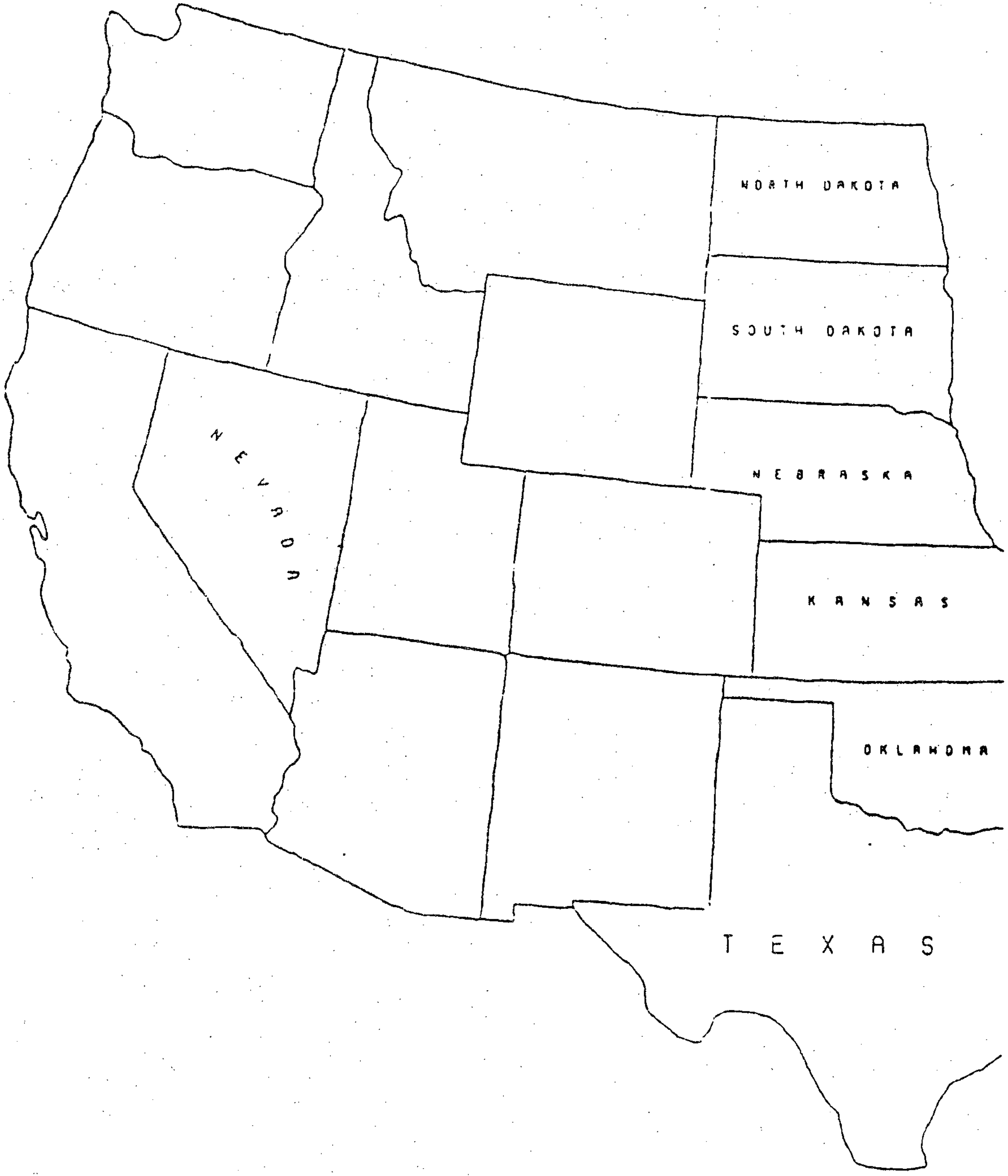
EXAMPLE OF AREA-FEATURE NAME PLACEMENT



USING THE SHAPE SKELETON SCHEME TO PLACE AN AREA-FEATURE NAME



PLACEMENT OF AREA-FEATURE NAMES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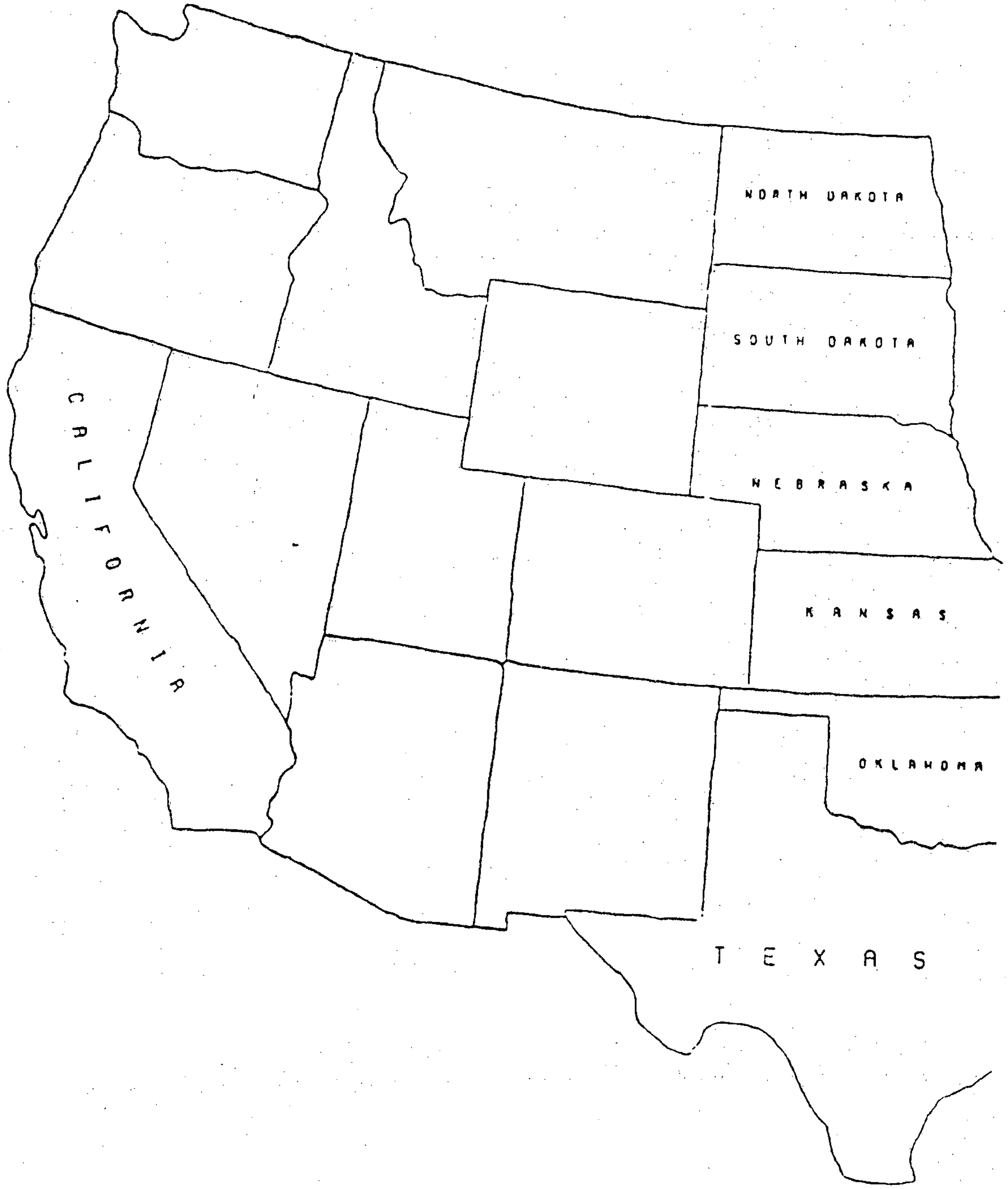
SOUTH DAKOTA
NEBRASKA
NEVADA
KANSAS
OKLAHOMA
TEXAS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CALIFORNIA
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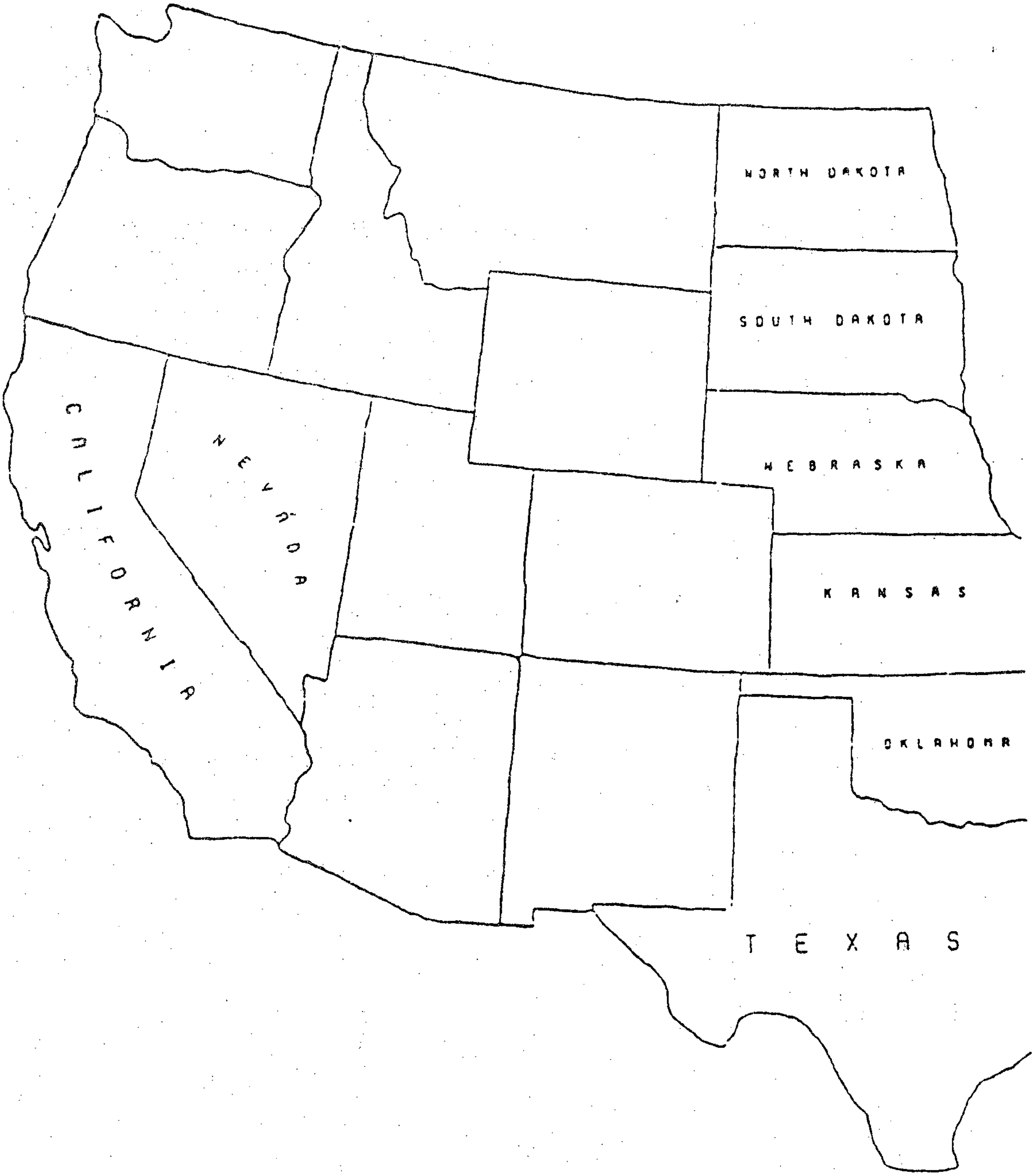
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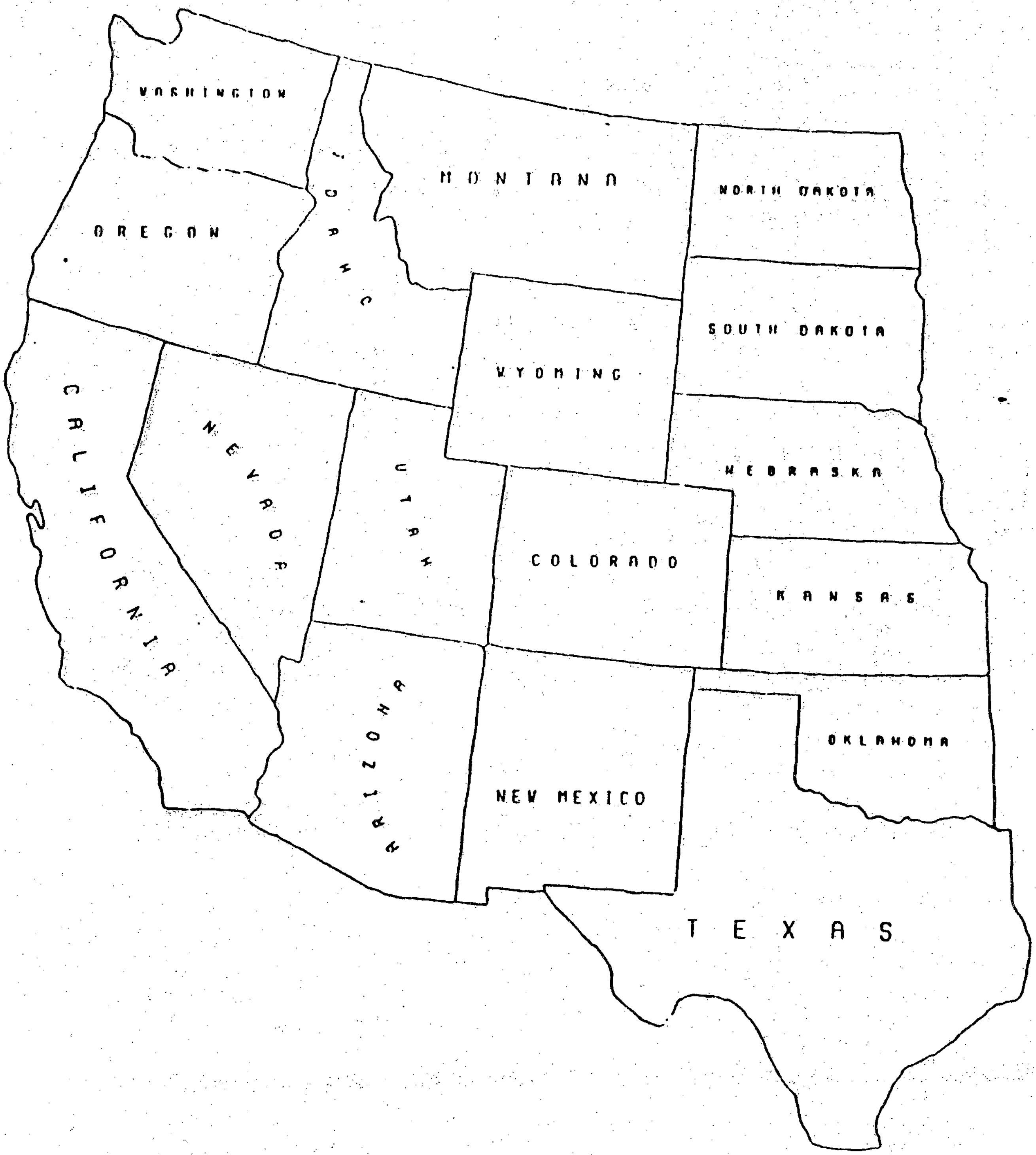
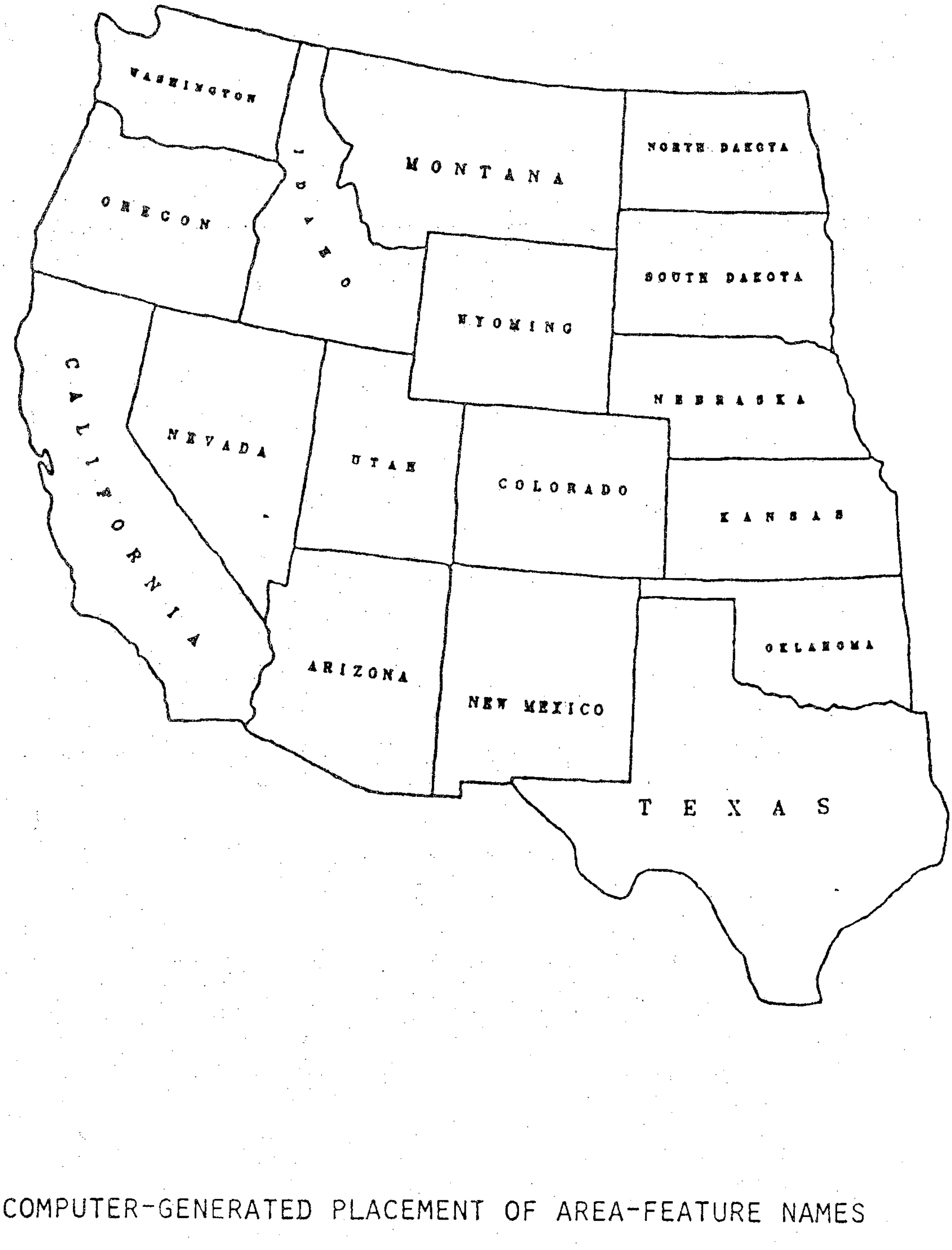
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
CALIFORNIA
NEVADA



COMPUTER-GENERATED PLACEMENT OF AREA-FEATURE NAMES



COMPUTER-GENERATED PLACEMENT OF AREA-FEATURE NAMES

GUIDELINES FOR POINT-FEATURE NAME PLACEMENT

1. NAME SHOULD BE HORIZONTAL (EAST-WEST) AND NOT CURVED.

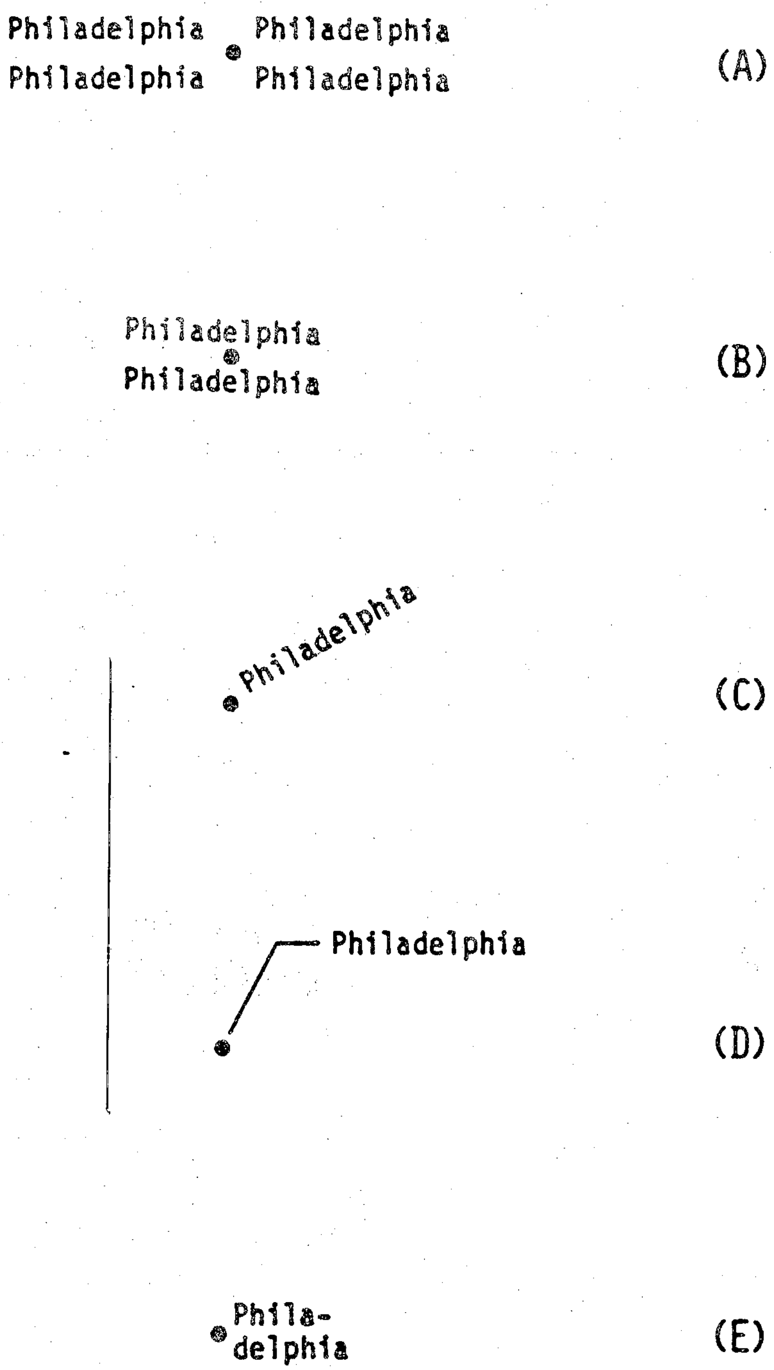
2. NAMES SHOULD NOT BE SPREAD OUT.

3. NAMES SHOULD BE SOME SMALL DISTANCE AWAY FROM POINT FEATURE.

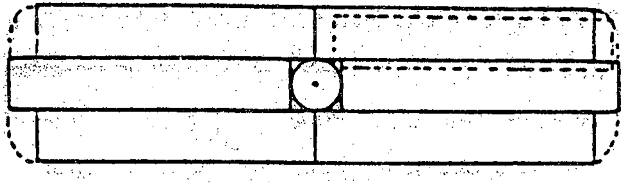
4. NAMES SHOULD NOT BE MORE THAN SOME MAXIMUM DISTANCE AWAY FROM POINT FEATURE. (DIFFERENCE BETWEEN MINIMUM AND MAXIMUM IS VERY SMALL.)

5. PLACEMENT OF NAME **ABOVE** THE FEATURE IS PREFERRED OVER PLACEMENT BELOW.

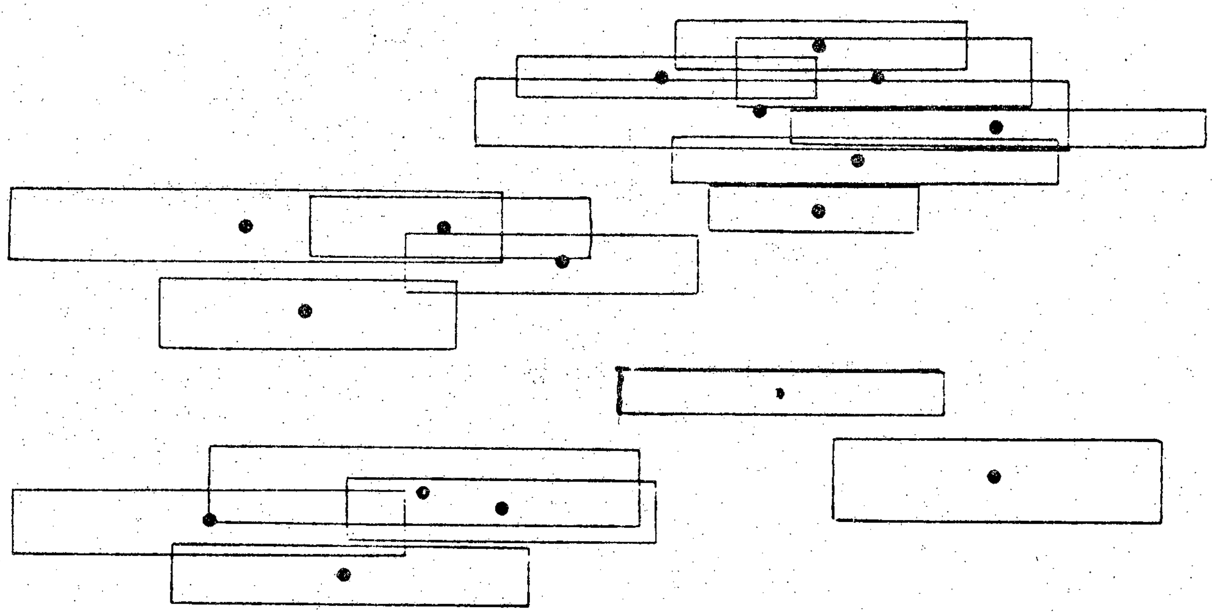
6. AT A COASTLINE PREFERRED NAME PLACEMENT IS "IN THE WATER".

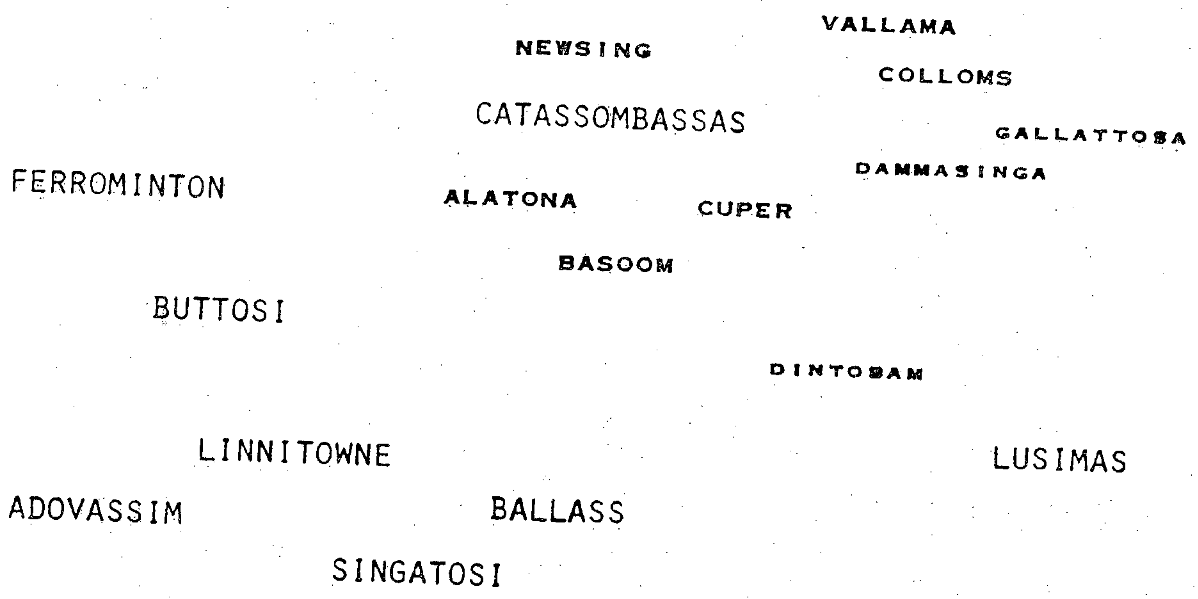


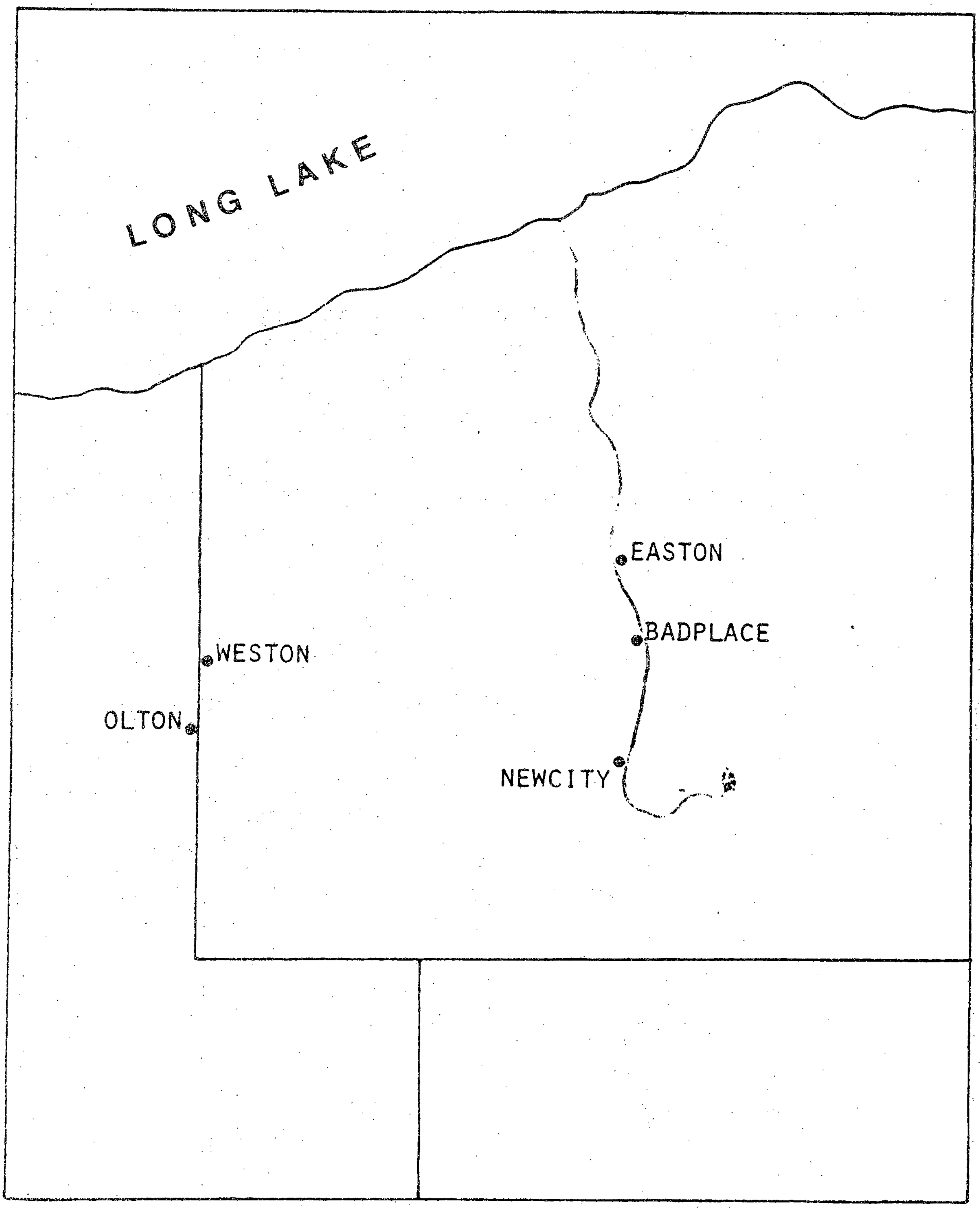
POINT-FEATURE NAME PLACEMENT POSSIBILITIES

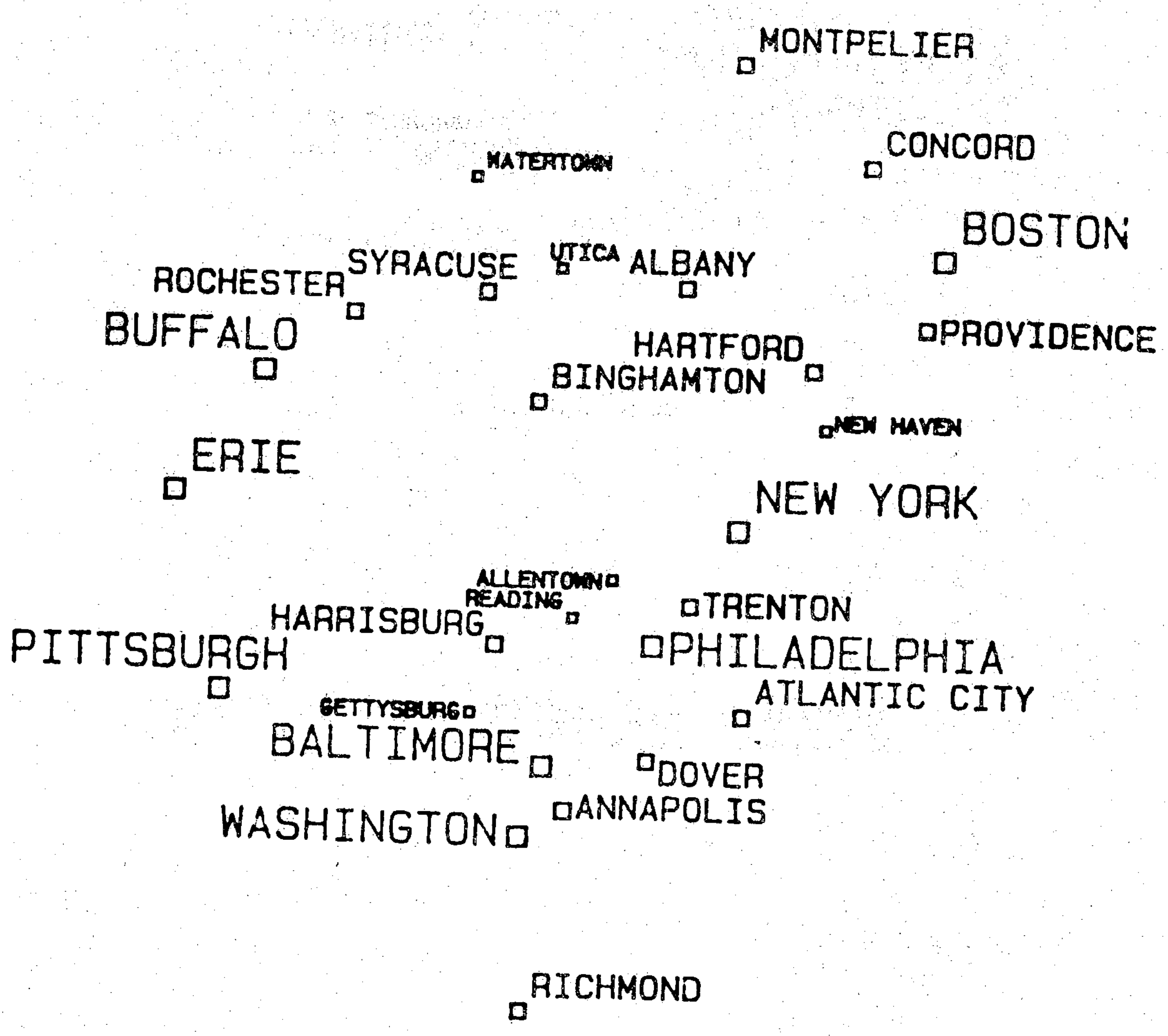


PREFERRED POSITIONS FOR POINT-FEATURE NAME PLACEMENT



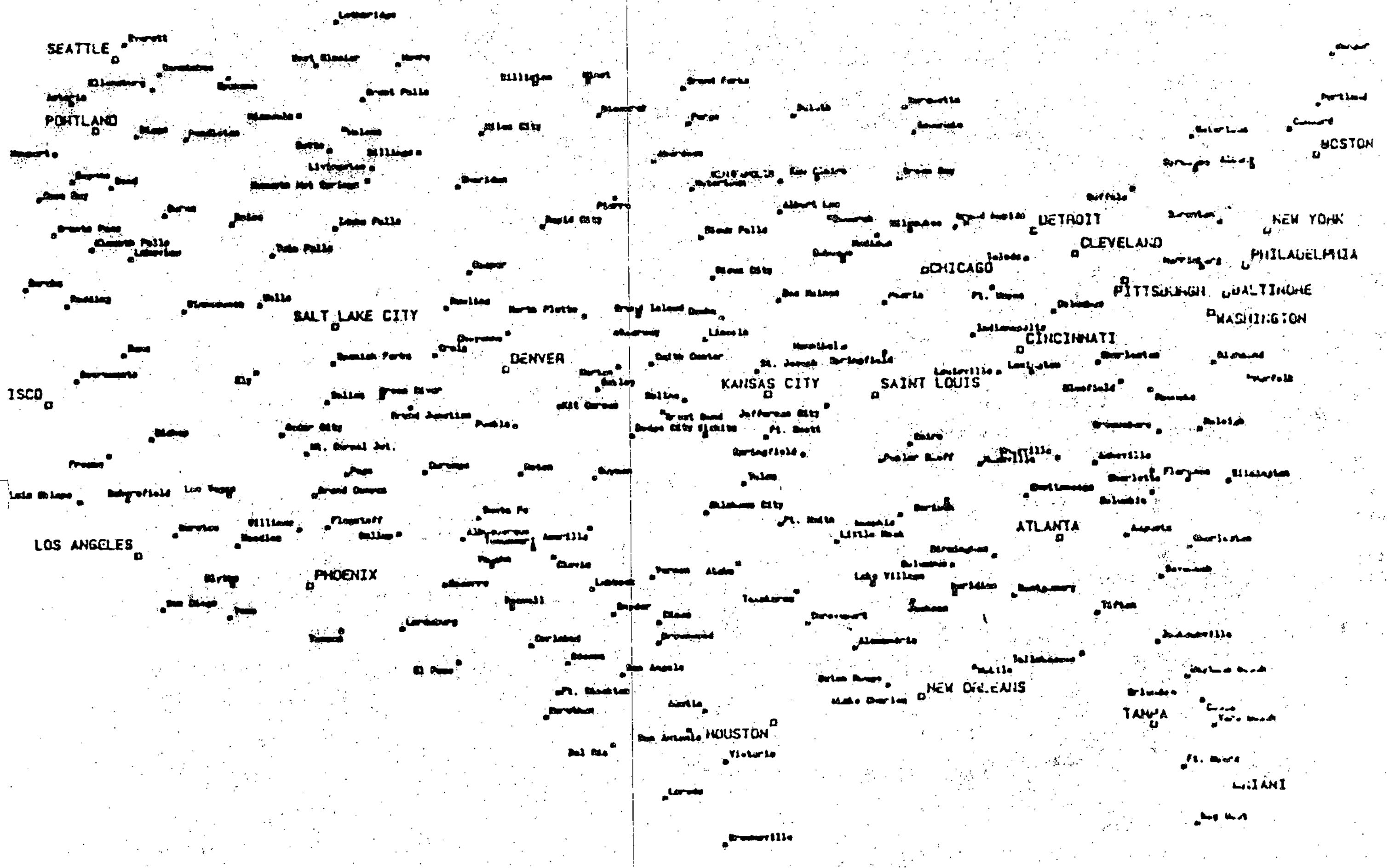

VALLAMA
NEWSING
COLLOMS
CATASSOMBASSAS
GALLATTOSA
DAMMASINGA
FERROMINTON
ALATONA
CUPER
BASOOM
BUTTOSI
DINTOSAM
LINNITOWNE
LUSIMAS
ADOVASSIM
BALLASS
SINGATOSI


LONG LAKE
EASTON
BADPLACE
WESTON
OLTON
NEWCITY



EXAMPLE OF POINT-FEATURE NAME PLACEMENT

EXAMPLE OF COMPUTER-GENERATED POINT-FEATURE NAME PLACEMENT



EXAMPLE OF COMPUTER-GENERATED POINT-FEATURE NAME PLACEMENT

GUIDELINES FOR LINE-FEATURE NAME PLACEMENT

1. NAME PLACEMENT SHOULD CONFORM TO CURVATURE OF LINE FEATURE.

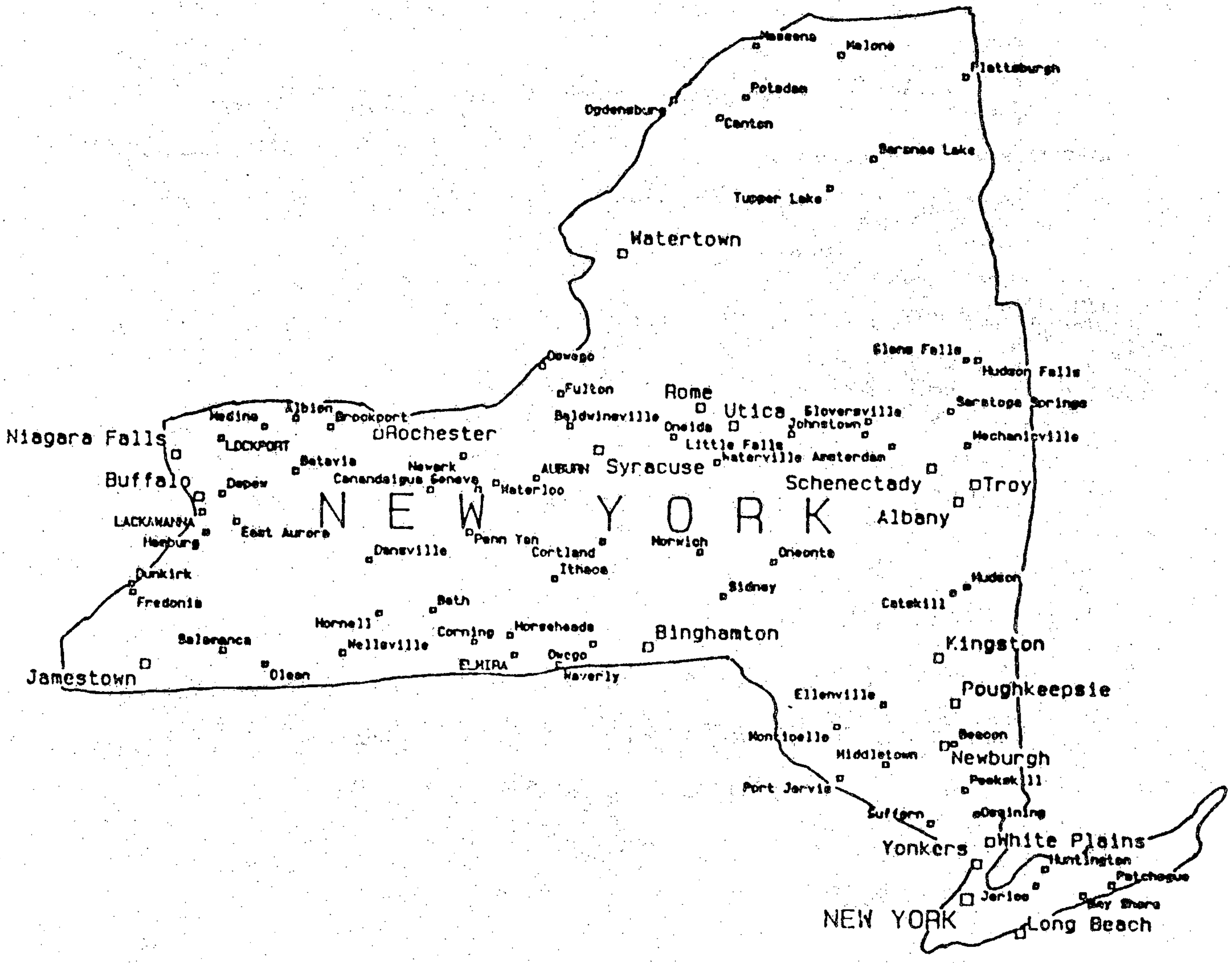
2. COMPLEX AND EXTREME CURVATURES SHOULD BE AVOIDED.

3. NAMES SHOULD NOT BE SPREAD OUT BUT MAY BE REPEATED AT INTERVALS ALONG LINE FEATURE.

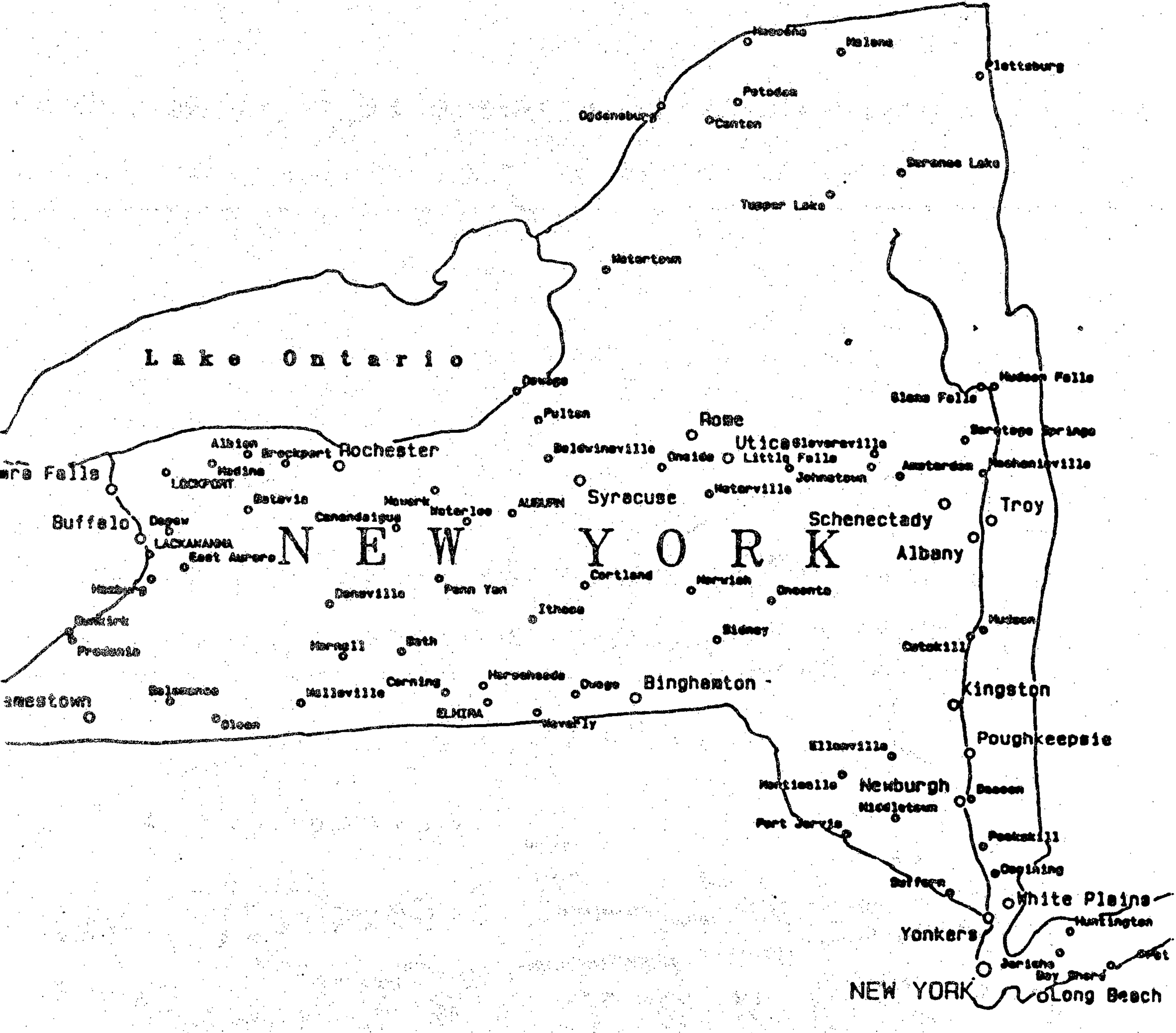
4. FOR HORIZONTAL FEATURES, NAME SHOULD BE **ABOVE** FEATURE.

5. FOR VERTICAL FEATURES IN LEFT HALF OF MAP, NAME SHOULD BE TO LEFT OF FEATURE AND READ UPWARD. IN RIGHT HALF OF MAP, NAME SHOULD BE TO RIGHT OF FEATURE AND READ DOWNWARD.

6. NAME SHOULD NOT BE PLACED TOO CLOSE TO FEATURE ENDPOINT.



EXAMPLE OF COMPUTER-GENERATED, COMBINED POINT- AND AREA-FEATURE NAME PLACEMENT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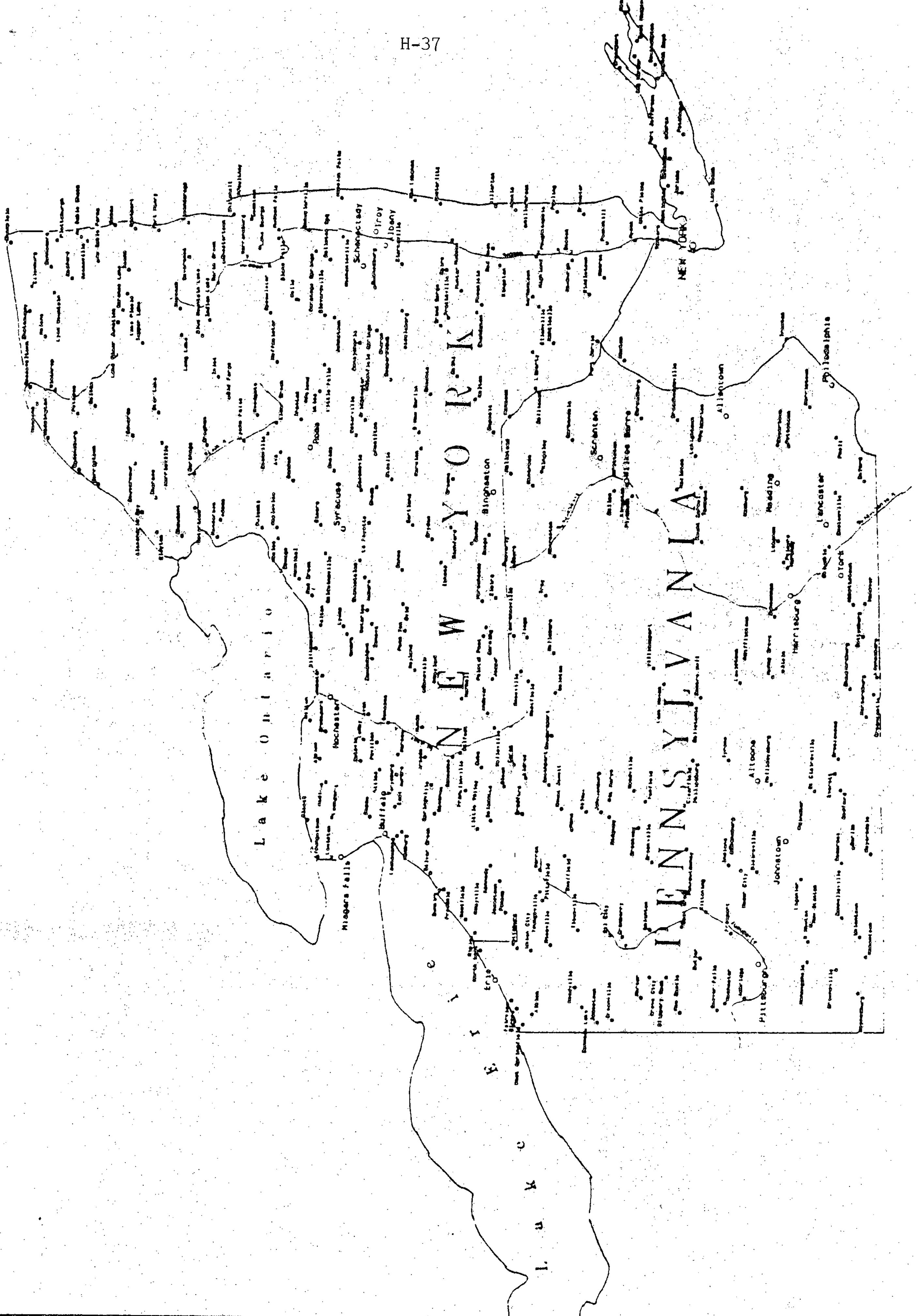
Massena
Malone
Plattsburg
Potsdam
Ogdensburg
Canton
Saranac Lake
Tupper Lake
Watertown
Oswego
Fulton
Rome
Utica
Gloversville
Little Falls
Johnstown
Glens Falls
Hudson Falls
Saratoga Springs
Mechanicville
Amsterdam
Troy
Schenectady
Albany
Albion
Brockport
Rochester
Medina
Lockport
Batavia
Baldwinsville
Oneida
Waterville
Syracuse
Newark
Waterloo
Auburn
Canandaigua
Buffalo
Depew
Lackawanna
East Aurora
Hamburg
Dunkirk
Fredonia
Cortland
Norwich
Oneonta
Penn Yan
Dansville
Ithaca
Sidney
Catskill
Hudson
Hornell
Bath
Corning
Horseheads
Owego
Binghamton
Kingston
Salamanca
Wellsville
Olean
Elmira
Waverly
Poughkeepsie
Ellenville
Monticello
Newburgh
Beacon
Middletown
Port Jervis
Peekskill
Ossining
Suffern
White Plains
Huntington
Yonkers
Jericho
Bay Shore
NEW YORK
Long Beach


NEW YORK
PENNSYLVANIA
Lake Ontario
Lake Erie
New York
Albany
Troy
Schenectady
Syracuse
Binghamton
Rochester
Buffalo
Niagara Falls
Erie
Scranton
Wilkes Barre
Allentown
Philadelphia
Reading
Lancaster
York
Harrisburg
Altoona
Johnstown
Pittsburgh

APPENDIX I: NOTES FROM GROUP 1

This appendix contains additional information intended to provide further background on the thinking of the working group. The submissions it contains were stimulated by working group discussion and generated during and at the close of the workshop. They were not discussed during the workshop as such, but were in the hands of the workshop members after the workshop for their review and comment

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Proceedings I-2

Separate Submissions

Attachment A: Remote Sensing Needs and Specific Recommednations for NSF, George Zissis I-8

Attachment B: Discussion on the Intelligent Integration of Data Bases and Models (Expansion of last items in Table 3), George Zissis I-10

Attachment C: Research Topics in Visual and IR Remote Sensing Instrumentation, John Wellman I-12

Attachment D: Scene Modeling, Atmospheric Correction, and Radiometric Calibration, Philip N. Slater I-15

Untitled Submissions

Frederic Billingsley I-28
Richard Newton I-28
David Simonett I-29
Stephen Ungar I-30
Vern Vanderbilt I-30
George Zissis I-30

Membership

The members of Working Group I are listed below:

Dr. Philip Slater, University of Arizona (Chairman)
Mr. John Wellman, JPL (Scribe)
Mr. Fred Billingsley, JPL
Dr. Keith Carver, New Mexico State University
Dr. Herbert Freeman, Rensselaer Polytechnic Institute
Dr. Edward Mikhail, Purdue University
Dr. Richard Newton, Texas A & M University
Dr. David Simonett, U.C. Santa Barbara
Dr. Stephen Ungar, IBM Watson Research Center
Dr. Vern Vanderbilt, Purdue University
Dr. George Zissis, ERIM

Proceedings

The purposes of the Working Group's deliberations were to review the need for "basic engineering sciences" as an element of an earth observing remote sensing program and to identify "fruitful research paths" which would provide guidance in the selection of proposals to NSF for research funding.

The group elected to subdivide the broad topic area into three categories: (1) Physics and Scene Characterization, (2) Sensing, and (3) Data Processing/Information Extraction. To clarify the distinctions implied, a list of key words were developed for each category with the recognition that the list would be incomplete (but helpful in a suggestive sense) and that many subject areas would overlap several categories.

Physics and Scene Characterization was construed to contain the basic sciences of the interaction of radiation with matter including the establishment of models to describe the interactions. Key words were electromagnetic interactions, Fraunhofer line imaging, radar, lasers, experimentally obtained data bases, spatial modelling, sampling, physical "point" and "area" models, and experiment. Of the three categories, physics and scene characterization was deemed to be more scientifically focussed but fundamental to the engineering sciences more directly discussed in the remaining two categories.

Sensing is the process of taking measurements, often by remote sensing techniques and includes the development, use, and understanding of instruments, as well as the platforms from which measurements are made. Key words were new technologies; detectors; sensor development; platforms; geometric, radiometric and atmospheric correction; and calibration.

Data Processing/Information Extraction included the theory, technique, hardware and software for handling and processing data; deriving information; and comparing experimental results with theory and models. Key words were developments in information processing; developments in mass data storage; algorithm development; atmospheric correction; and integration of remote sensing, Artificial Intelligence (AI), and Geographic Information Systems (GIS).

For each of the three categories, the group identified the current limitations or problems and proposed the types of research needed to address the problems. The results of this process are given in Tables 1 through 3.

TABLE 1. Physics and Scene Characterization

Limitations/Problems	Research Needed
1) Scattering Matrix for radar -- by frequency, polarization, resolution, and look angle.	For μ-wave, one needs full scattering matrix for bistatic geometrics.
2) Spectra, BRDF, polarization (optical) for land, oceans, atmosphere.	Spectropolarimetric studies
3) Atmospheric-induced polarization of radiation.	
4) Resolution distribution for natural/man-made scenes.	More general studies of high resolution scale dependence of information (from aircraft data.)
5) Lack of model parameter sensitivity studies.	Sensitivity studies of model parameters.
6) Theoretical, physical models whose parameters/values are measureable.	Optimize parameter insensitivity in invertable models.

Table 2. Sensors

Limitations/Problems	Research Needed
High Data Rates (10 bit terabit/s A/D conv.) High power requirements for radar and other sensors. Lack of data on spectral optical depth.	Avoid by O/B processing, data compression bistatic, radar, new design.
	VHSIC and other improved electronic devices; analysis of absorption bands, Langley and Fourier comp. analysis
Photon Shortage.	Greater throughput optical systems.
Inadequate spatial resolution.	BLIP detectors in IR, large or large or adaptive optics.
	Improved spaceborne cooling systems.
Lack of polarization mesurements and sensors.	Development of polarization sensitive sensors.
Inadequate temporal resolution.	Solar powered high altititide airaircraft.
Inadequate data base in passive microwave.	Spatial vs temporal resolution trade.
Control Point deficiency	Studies of control points, contrast number and distribution; suitability to radar data.
	Location of pixels in absence of control points (study of ephemeris, pointing, etc.).
	Consideration of MAPSAT and other alternatives.
	Characterization of spatial response of detector arrays.
Difficulty of achieving radiometric stability (radar).	Further study of stability -- antenna stabilization.
Difficulty of radiometric calibration and stability (optical).	Characterization of spectral response of detector arrays.
	Improved on-board calibration techniques.
Difficulty in calibrating polarization of sensors (optical).	Improved polarization measurement techniques.

Table 3. Data Processing/Information Extraction

Limitations/Problems	Research Needed
Lack of:	
1) Serial Processing	Structuring execution of remote sensing algorithms for parallel machines
2) Parallel Processing Programming	Parallel Hardware Architecture
3) Language for spatial processing	Development of parallel processing language(s) for processing spatial operations
SAR processing limited by FLOP speeds (3 GFLOP needed)	Hybrid optical/digital processing
Lack of knowledge on how we solve spatial problems in at least 3 dimensions	Development of expert systems for remote sensing
Data storage capacity and storage rate	Economic reliable ways for archival data storage
	Effect of data compression on recovery of information
	Data Organization
Inadequate GIS	
1) for space data 2) for integration of other data	Integration of other spatially-related data through AI computer-assisted selection processing, and integration of data bases using externally derived logic, in a manner directed to calculation of models/simulations; e.g., use of models to determine radiance distribution at sensor over the scene; e.g., given scatterometer observations of sea state to deduce wind yield; e.g., given passive and active μ-wave observations, deduce soil moisture distributions; e.g., use of simulation for data evaluation and for information extraction

Separate Submissions

Several members of the group have submitted additional material either clarifying the meanings of entries in the tables or providing a more detailed listing of fruitful areas of engineering research. These separate submissions were not reviewed by the group as a whole other than in the course of individually reviewing this manuscript. They are listed below and included as appendices to this report:

Attachment A.	Remote Sensing Needs and Specific Recommendations for NSF, George Zissis
Attachment B.	Discussion on the Intelligent Integration of Data Bases and Models (Expansion of last items in Table 3), George Zissis
Attachment C.	Research Topics in Visual and IR Remote Sensing Instrumentation, John Wellman
Attachment D.	Scene Modeling, Atmospheric Correction, and Radiometric Calibration

Attachment A. Remote Sensing Needs and Recommendations for NSF

George Zissis

What research should be done by year 2000 to more rapidly advance the technology of remote sensing? What are the gaps most appropriately addressed by NSF (Engineering Sciences Division)?

Remote sensing needs especially:

1) Better and more complete predictive phenemena - logical models which can use physical characterization of materials (their properties and their states) in any scene and allow one to calculate the sensing system input.
2) An improved experimentally-obtained data base with which one can test the models and determine their fidelity for system performance end-to-end evaluation.
3) Sensor characterization allowing the completion of the scientific process, i.e. hypothesis, experiment design (including instrumentation), experiment execution, evaluation of results, comparison with the predictions, modification of the hypotheses, and new experiment design.

Specific recommendations/suggestions:

1) A series of projects are needed to help user scientists formulate questions in their fields but in terms of remote sensing. Examples: soil scientist working with remote sensing scientist to model processes in terms of remotely observable characteristics; cloud physicist/meterologist to team with remote sensing scientist for model and experiment plan verifying model.

2) Education programs in remote sensing systems engineering should be developed.

3) Designs should be made for low-cost, highly-mobile, data-gathering probes which are relatively intelligent and can operate in relatively hostile environments. Examples: remotely piloted vehicles for atmospheric probes; deep sea-ocean bottom traversing sensing robots.

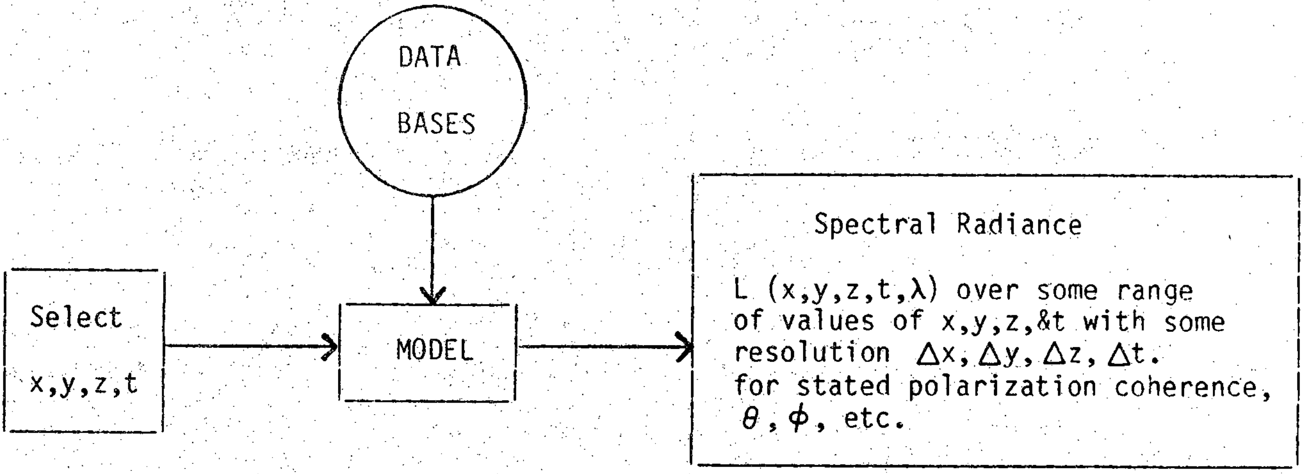
4) A broad study of active sensing systems should consider points of commonality for systems which include any deliberately induced perturbation (of a small selected region of the system being observed) in order to gain information from remote observations of the disturbed region.

5) Studies are needed of the multisensor systems which use a common platform compared to separate platforms (using individual sensing systems) used in a coherent, integrated remote sensing experiment. Analysis should consider different points of unification ranging from common apertures, common platforms, or merged data streams into common data processing; to separate "platformed" systems leading to unification only at the level of extracted information.

Attachment B. Discussion on the Intelligent Integration of Data Bases and Models

(Expansion of Last Items in Table 3)

George Zissis



Uses of this model output:

1) Evaluation of Sensor System (Characterization/Calibration/etc)
2) Inverting from remote sensing system output to an accurate description of that being observed.

Needs:

Data Bases with data indexed by space, time, etc. Include those calculable from external as well as internal factors; ie. solar spectral irradiance at earth at x, y, z, t, etc: atmospheric parameters of T, P, aerosol concentration (size, clouds, etc; maps; data at some values of $t - \Delta t_1$, $t - \Delta t_2$, etc.)

Models - allowing calculation of available radiant signal at the sensor. For 2) above, means to select/correlate/integrate all of these data, exercise the models, and be helped in the logical chain from observation (with data models) to deduction.

For 1) above, Sensor parameters (e.g. resolution, dynamic range, etc.) and relations needed for the capability to calculate (i.e. simulate) system output given any well-defined input.

The understanding of the equations to calculate both 1) and 2) is adequate - the problem is one of formatting and implementing the capability in computer form.

Attachment C. Research Topics in Visual and IR Remote Sensing Instrumentation

John Wellman

I. Infrared Detector array development
  A. Improved materials and processes development
    1. Near-Term
      a. OMCVD (Organo-Metallic Chemical Vapor Deposition)
      b. LPE (Liquid Phase Epitaxy)
      c. Molecular Beam Epitaxy
      d. Cluster Beam Epitaxy
    2. Long-Term
      a. Superlattices
      b. Other
  B. Characterization and control of surface electro-optic properties
  C. Advanced device structures performance modelling
  D. On-chip signal processing
    1. Preamps, Floating Gate Amplifiers
    2. Filters
    3. Summing, Arranging
    4. Fill & Spill, Charge division

II. Optical Design
  A. Wide field, wide spectral range imagers
  B. Imaging Spectrometers (esp. flat focal plane designs)
  C. Spectral dispersing techniques
  D. Polarization reduction
  E. Polarization measurement
  F. Coating and Dichroics

- G. Uniform spectral filters
- H. Linearized prisms
- I. Beamsplitter/prism assemblies
- J. Lightweight optics
- K. Onboard calibration methodology

III. Space Coolers

- A. Lower temperature (80°C), higher heat load, long life coolers
  - 1. Radiative
  - 2. Joule-Thompson
  - 3. Thermo-electric
  - 4. Solid cryogen
- B. Low temperature heat pipes

IV. Structures and Thermal Control

- A. Athermalized metering structure
  - 1. Active (w. heaters)
  - 2. Passive
- B. Active alignment systems
- C. Optical mounts
- D. Precision actuators and mechanisms

V. Electronics/On-board data processing

- A. High Speed A/D Converters
- B. Fast Processors (Array/Pipeline)
- C. Data Compression

VI. Information Extraction

- A. From high dimensionality data sets
- B. Data base management, synthesis with other data types

C. Calibration restoration

D. Use of programmable sensors (experiment operations)

VII. Interference Effects

A. Single event upsets in instrument or spacecraft electronics

B. Aurora effects

C. Contamination effects in spacecraft environment

D. Glow discharge around instruments in STS and other spacecraft

Attachment D

Scene modeling, atmospheric correction, and radiometric calibration

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The Problem

The use of satellite-acquired image data in scene models is inextricably dependent on atmospheric correction and sensor absolute radiometric calibration. Unlike automated scene classification, which depends on a statistical analysis of the digital counts in a scene image, usually without correction for the intervening atmosphere, modeling is concerned with determining the radiance of the scene. For this purpose we need to know, first, the output digital counts from the sensor when it is imaging the feature of interest, second, the absolute radiometric calibration of the sensor in order to convert the digital counts to radiance at the entrance pupil of the sensor, and third, the radiance modification introduced by the intervening atmosphere (the atmospheric correction) in order to relate the entrance pupil radiance to the radiance of the ground feature.

The problem divides into three parts: (1) determining to what accuracy we have to know the feature radiance in order to produce satisfactory data from the various models available--not a well understood relationship in many cases, (2) providing a means to make atmospheric corrections to a certainty commensurate with (1) above, preferably using the imaging sensor or a co-located system--even simple ground-based atmospheric measurements are rarely attempted today, and (3) providing in-flight absolute radiometric calibration to a certainty commensurate with (1) and (2)--the estimated ±10% uncertainties of the Landsat Thematic Mapper (TM) and the SPOT High Resolution Visible systems (SPOT/HRV) are unlikely to meet these needs.

Models

The main reason for developing models is to obtain quantitative and/or diagnostic information regarding specific areas or features or to study global phenomena. Examples of the former are to diagnose the cause for the loss of crop vigor or to determine and map chlorophyll concentration in prospective fisheries. Examples of the latter are global earth-atmosphere-ocean studies such as those envisioned by COSPAR's International Satellite Land Surface Climatology Project and those proposed as part of NASA's Global Habitability program.

A good source of information on the various models developed over the past decade can be found in recent reviews by Bunnik [1] and Smith [2]. Most of the models predict an upward radiance, just above the feature, on the basis of certain input values. For example, in the case of a crop canopy, the input values would include the leaf spectral reflectance and canopy geometry (leaf area index, LAI, and leaf orientation), the soil spectral reflectance, and the geometry of illumination and viewing. For many purposes the inverse form of this model is more valuable: Given the radiance and illumination and viewing geometry, what is the constitution (LAI, vigor, etc,) of the canopy? Goel and Strebel [3] have described such a model; however relatively little other work on inversion models has been reported.

The sensitivity of both direct and inversion models to measurement accuracies and assumptions needs much further exploration. In this respect it is interesting to note how various scientists working with models respond informally to the question "what sensor absolute radiometric calibration uncertainty can you tolerate in using your models?" The answers should represent the model's sensitivity.

1% J. L. Barker (Goddard Space Flight Center) in support of his layered concept. For example, the removal of atmospheric effects to obtain BRDFs followed by the use of the BRDF data to interpret subtle texture changes and natural variations.

3% N. J. J. Bunnik (NLR, the Netherlands) for vegetation and ocean model studies.

3% J. Dozier (UC Santa Barbara) for snowfield model studies.

0.5% D.G. Goodenough (Canada Centre for Remote Sensing) to provide the correction for change in sensor response with time, necessary for multi-temporal studies.

1% J. Gower (University of British Columbia) for ocean color studies, in particular chlorophyll concentration determination.

5% R. D. Jackson (Agricultural Research Service, Phoenix) for evapotranspiration models.

3% J. A. Smith (Colorado State University) for general model studies and plant canopy models in particular.

These responses deserve more detailed study. In particular it is important to determine, for each response, whether: (1) absolute radiometric calibration meant a calibration in physical units (radiance) or a stability of relative calibration (in digital counts) with time, (2) it was assumed that atmospheric effects had been perfectly corrected, and (3) these values were well corroborated and a study had been made to determine information loss as a function of calibration uncertainty.

The literature describing the use of models for the analysis of satellite acquired digital image data is meager. The work of Aranuvachapun and LeBond [4], Doak et al. [5], Gordon [6], Kowalik et al. [7], Otterman and Fraser [8], and Robinove et al. [9] represent perhaps the most significant contributions. The lack of reported results can be related to (1) the difficulty of making accurate atmospheric corrections, (2) the large uncertainty in sensor absolute radiometric calibration, and (3) the fact that not many models have been developed and their experimental testing and exploitation involve considerable effort.

Atmospheric Correction

There was a flurry of activity in atmospheric correction in the first year of the Landsat program and during the Skylab program. A review of much of this work has been provided by Slater [10]. The activity was caused by concern regarding the magnitude of atmospheric path radiance, that is, atmospherically scattered light that is added to the radiance of the scene but that contains no information concerning the scene. An example of its magnitude is that under clear atmospheric conditions, at a wavelength of 0.55 μm and for a ground reflectance of 0.1, the atmospheric path radiance at the entrance pupil of a satellite sensor is as large as that due to the radiance from the ground.

Except for those investigations mentioned in the last section, [4] to [8], little additional work has been done on atmospheric correction. This can be attributed to the emphasis in the 1970s on the statistical analysis of image data, which did not necessitate correction for the atmosphere, and to the lack of accuracy of the results of those early investigations. The latter was due mainly to three reasons: (1) The atmospheric models were inadequate. For example, they did not account for multiple scattering and/or they did not account for the adjacency effect (see later). (2) The difficulty of completely characterizing the atmosphere forced the investigator to make many assumptions, which introduced large uncertainties in the result. (3) There was no convenient way to check the accuracy of the results or use them because of the large uncertainty in the in-flight absolute radiometric calibration of the aircraft and spacecraft sensors involved.

The studies of Ahern et al. [11], Dana [12], Dozier and Frew [13], Holyer [14], Kriebel [15], Lyon et al. [16], Munday [17], Price [18], Richardson [19], and Watson and Hummer-Miller [20] describe some different recent attempts to correct or allow for the atmosphere. The following methods are among those currently in use.

Gordon et al. [6] have described a method for the atmospheric correction of Coastal Zone Color Scanner data. It uses a Monte Carlo atmospheric radiative transfer model and an algorithm which includes a ratio of the aerosol optical depth in the visible to that at 670 nm, where the reflectance of the ocean is assumed zero. As Aranuvachapun [21] points out, the accuracy of the algorithm relies mainly on the accuracy of this ratio, which is presently not measured by satellite remote sensing. The uncertainty of the method in determining pigment concentration is stated to be 30-40% over the concentration range 0.08-1.5 mgm^{-3}. In three direct comparisons between ship-measured and satellite-determined values of the water radiance, the Gordon et al. atmospheric correction algorithm is claimed to have an average error of 10-15%. Their method does not require any surface measurements at the time of the satellite overpass.

A method making use of ground-based measurements at White Sands, New Mexico, has been described by Castle et al. [22] and Kastner and Slater [23]. Its limitation is that, although it has a low uncertainty (about ±3%), it cannot readily be used for other areas, first because it involves ground-based measurements and second because at other locations its accuracy may be compromised by the adjacency effect.

The adjacency effect, first analyzed by Pearce [24] using a Monte Carlo method and also by Dave [25], describes the influence of atmospheric crosstalk in modifying the radiances of adjacent fields of different radiances. Pearce showed that the effect can extend over large distances. For example, if the Thematic Mapper were to image two semi-infinite planes of reflectances 0.5 and

0.1 at a wavelength of 0.55μm under normal atmospheric conditions, the radiance of the lower reflectance area, 1 km from the edge, would appear to be 10% more than its asymptotic value.

Methods for compensating for the adjacency effect have recently been described by Tanre et al. [26], and Kaufman and Fraser [27]. Three experiments have been conducted in attempts to verify the adjacency effect. Mekler et al. [28] made a laboratory simulation in which the atmosphere was simulated by latex spheres suspended in water. The measured effect was found to be 20% larger than that predicted by Pearce [24]. Kaufman et al. [29] flew an aircraft in hazy conditions (aerosol optical depth ~1.0 at 510 nm) and demonstrated the existance of the effect. Dyche [30] in a very clear atmosphere (total optical depth 0.3 at 440 nm) showed the effect may exist but at a level that is difficult to detect under such good conditions.

Methods for the on-board determination of atmospheric correction factors, which make use of multiple ground views from a pointable sensor, have been suggested by Diner [31] and Slater and Martinek [32]. These suggestions are preliminary and require further development and testing.

Sensor Absolute Radiometric Calibration

Accurate in-flight absolute radiometric calibration is useful for:

1. Providing a radiance input to physical models describing the interaction of electromagnetic radiation and the earth's surface and atmosphere.
2. Determining the temporal stability of sensor radiometric response.
3. Providing a means to intercompare the responses of, and therefore the data from, different satellite systems.

Attempts to provide accurate in-flight absolute radiometric calibration of land remote sensing systems have not been successful. In 1972 the sun calibrator system on the Landsat I Multispectral Scanner System, which was intended to provide absolute calibration, exhibited a remarkable change in its response. After 21 orbits the 0.5 to 0.6 μm band calibration had decayed to 7% of its preflight value [33]. The other bands showed pronounced but smaller changes. The sun calibrator system has not been used on any of the Landsat MSSs since. Barker et al. [34] have estimated the preflight absolute radiometric calibration of the TM to be about ±10%. Norwood and Lansing [35] state that it is no better than ±6.8%. Dinguirard and Maisoneuve [36] have estimated the absolute radiometric calibration of the SPOT/HRVs to be ±10%. The calibration methods employed for TM and SPOT/HRV and their shortcomings have been described in detail by Slater [37].

In an effort to reduce the uncertainty in the absolute radiometric calibration of TM-5 and the SPOT/HRVs, NASA and CNES are supporting work at NOAA and the University of Arizona. The NOAA work for NASA has been described by Hovis [38]. It involves an in-flight calibration of TM using an approach similar to that mentioned earlier for the CZCS [5]. The NOAA work for CNES involves a check of the MATRA preflight absolute calibration using an integrating sphere; the accuracy of the sphere method is described by Hovis and Knoll [39]. This check will also provide a comparison between the SPOT and TM calibrations. The University of Arizona work for both NASA and CNES involves the in-flight absolute calibration of the TM, MSS, and SPOT/HRVs with reference to White Sands; see Castle et al. [22] and Kastner and Slater [23]. It is hoped that the calibration work of NOAA and the U of A in support of the TM and SPOT/HRV will reduce the in-flight uncertainties in absolute calibration of these systems to the ±3 to ±5% level.

Research Needs

From the above discussion, the following interdependent research studies can be identified:

1. The accuracy of the data provided by scene and atmospheric radiative transfer models, particularly inversion models and those that include polarization, needs to be related to the type (radiance or digital counts) and the accuracies of input values, atmospheric correction, and sensor absolute calibration.

2. Detector-based calibration methods need to be extended from the present range of 0.4 μm to 0.8 μm, which makes use of silicon detectors, to at least 3 μm using other detectors.

3. Atmospheric correction methods using ground-based reflectance and atmospheric measurements need to be improved, and atmospheric correction methods need to be developed that can be conducted using the image acquisition system itself or an auxiliary co-located system.

4. An experimental investigation needs to be conducted to determine the degree to which the adjacency effect can be accurately modeled and compensated for.

5. Ways to completely characterize the absorption and scattering properties of the atmosphere need further study. Ground and intermediate altitude measurements need to be made to check assumptions regarding aerosol characteristics. There needs to be an extension of LIDAR and spectropolarimetric measurement methods for aerosol characterization, particularly from space, and the further development of atmospheric inversion methods.

6. Accurate on-board methods for absolute calibration, including the means for accurately monitoring any wavelength shift of the spectral passbands and

characterizing the polarization properties of the sensor, need to be developed. Methods for determining the in-flight absolute calibration using measured ground scenes and correcting for the intervening atmosphere need to be refined.

In conclusion, the exploitation of scene models in satellite remote sensing requires that considerably more research be devoted to developing: (1) accurate atmospheric corection procedures, preferably using data derived from a satellite sensor, and (2) in-flight methods for accurately radiometrically calibrating, in an absolute sense, future multispectral imaging systems used for earth observations.

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Frederic C. Billingsley

Determine the forward models which are used to select parameters for observation. This includes: physics of the sensing; intended analysis method; spatial relations; inter-sensor interactions; loss functions-param limits; preliminary data gathering and analysis attempts/demos; and data system facilities.

Develop information (into extraction model) models and the techniques which make the models solvable for using the potentially available data: multi-discipline; spatial relations; as related to "modern" computer technology (particularly MIMD techniques); estimations of loss (accuracy, utility....) functions; utility of data system aids - catalog access, browsing, promptness, geocoding, registration, etc.

Richard W. Newton

1. In the microwave portion of the spectrum it is important to begin to investigate the full scattering matrix to determine its value in extracting information about area extensive scenes. This will involve theoretical work and sensor work since we do not have sensors capable of measuring full scattering matrix now.

2. Begin to fund "engineering science". For instance, it is important to fund research to retime the effect of the sensor system on the measurement. This is critical in the microwave portion of the electromagnetic spectrum. Theoretical models are used to compute parameters that sensors are supposed to measure. However, the sensor never measures these parameters exactly. There is always contamination. Sometimes (as in the case of polarization) there are inherent definition differences between the model and the sensor capabilities!

3. Continue to fund development of models that describe the interaction of electromagnetic energy with matter - but stress that these models should be such that they describe the physical basis of this interaction. (Models that have unmeasurable parameters as inputs do not help in describing the physical basis.)

David S. Simonett

Proposition

1. Remote sensing will not mature until it is incorporated into and becomes an integral part of an AI/Geographic Information System. Indeed, both technologies need to mature together. These are deep-rooted and fundamental studies needed, however, on the spatial interaction effects and aggregation/disaggregation effects of employing multiple layers in GIS, along with remote sensing-derived layers. Studies are needed in particular on the structured logic needed to both simulate human image analysis and to avoid artefacting, and in the employment/development of physically-based models which may appropriately be exercised. In short, basic thinking and algorithm development are needed.

Recommendation

1. That NSF fund studies on algorithm development for both physically-based models and structured logic, for the more effective employment of remote sensing. These studies should be carried to the point of high computational efficiency, not only basic algorithm development.

Proposition

2. Despite the large sums spent on remote sensing, there is a serious lack of spectral studies, employing fine spectral resolution (10 mm). Such studies are needed not only for the fundamental science, of energy-matter interaction or the natural and biological sciences, but also for resolution of engineering design questions for future A/C and spacecraft instrument development. Jet Propulsion Laboratory A/C spectral systems, now under deployment, offers a superb opportunity to develop a separate University insight on the complex reality of multiple variable band selection for optimizing sensors. It is now flying and NSF might reasonably fund a number of investigations of joint engineer/natural scientist teams.

Recommendation

2. NSF should fund a small number of well designed experiments submitted by joint engineer/natural scientist teams or the natural science/engineering design questions arising from AIS spectral studies.

Steven G. Ungar

Need:

Fundamental research for characterizing (modeling) temporal and spatial variations of "scenes" (e.g. land use patterns) and relate parameters of this characterization to remotely sensed observables.

Nature of remotely sensed observables coupled with spatial and temporal scale needed to adequately describe land processes (scene) of interest should be used to define observing system specification and observation strategy.

Simulation studies (relatively low cost) can be used to determine sensitivity to changes in "optimal" observing system spec's as well as testing candidate observing system scenarios.

Appropriate sensor development and instrumented "experiments" (e.g. from aircraft or shuttle) requires as proof-of-concept prior to full scale activity.

Vern C. Vanderbilt

Measurements of the linear polarization of the scene should be made using sensors on the shuttle. Theoretical modeling and measurement studies should be undertaken to further investigate the effect of the atmosphere on polarized light reflected from the earth surface.

George J. Zissis

The major points which come to mind are:
NSF should solicit proposals in these areas:
1. a series of research projects involving jointly the aspects of physical phenomena (for the modeling and hypo thesis formulation), sensor scientists/engineers (for sensor design and sensor-phenomena interactions) and data processing researchers (for design of information extraction and hypothesis interaction). The hypotheses can be in any "remote sensing-user" science. 2. education in the engineering sciences aspects of remote sensing 3. research into the phenomenological models and bases for active electromagniral sensors (at all wavelengths) and for multi sensor systems 4. study of the use of small, mobile, intelligent probes capable of independent multiple data gathering ventures in

hostile environments (e.g., ocean bottoms, upper atmosphere) 5. an examination of the effects of data gathering modes for general classes of sensors upon the data processing methods (e.g., non-point-restricted data gathering sensors) and data processor

APPENDIX J: NOTES FROM GROUP 2

This appendix contains additional information intended to provide further background on the thinking of the working group. The submissions it contains were stimulated by working group discussion and generated during and at the close of the workshop. They were not discussed during the workshop as such, but were in the hands of the workshop members after the workshop for their review and comment.

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Warren A. Hovis J-5
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James Smith J-6
James C. Tilton J-6

Membership

The members of Working Group II are as follows:

- Prof. George Nagy (Chairman)
- Dr. David Goodenough (Scribe)
- Prof. Joseph K. Berry
- Prof. Morris Goldberg
- Prof. Robert M. Haralick
- Dr. Warren A. Hovis
- Dr. George H. Ludwig
- Prof. Robert E. McIntosh
- Ms. Virginia T. Norwood
- Prof. James A. Smith
- Dr. James C. Tilton

Joseph K. Berry

Future remote sensing technologies will impact society in two major ways. First, map products will take new forms. Contemporary products are limited to relatively static physical descriptions (e.g. tepographic, soils, etc). We currently monitor spatially changing phenomena (e.g., forest cover, land use, etc.) by acquisitioning periodic maps through statistical sampling. Future remote sensing products will provide, in map form, such scope of the data used in routine decision making.

The second major contribution will toe the development of a new processing orientation. The digital form of remote sensing products provides for new storage and analytic capabilities. Laser disk technology will enable thousands of maps to be economically and conveniently available to users. The digital form of these data will enable users to easily retrieve individual or composite maps. More importantly, users will be able to use computers to express spatial information in terms of decision parameters. A set of statistical and spatial reasoning operators will allow mapped data to be fully integrated into the decision-making process.

In short, remote sensing will change how the user community deals with spatial information:

*by supplying new types of information
*by providing a new processing methodology

General Thoughts on Workshop

1. The report would best summarize the future of R.S. if the initial list of recommendations is not constrained by perceived limitations (e.g., scientific merit, funding likelihood, political aspects, etc). We should outline the "pieces" of the future technology that are essential in making it useful to society. Several of these pieces are not "appropriate" for the NSF/R.S. project, but are appropriate for support by other funding groups, both within and external to NSF (e.g., platform/launch vehicle environments, education, etc.). If these elements are not addressed, advancements in "pure" remote sensing technology will not realize their full potential.

Tailoring the list of proposed activities to NSF should be done. The organization needs guidance in how it would best direct its support. It also needs to know the full set of necessary activities to fully capitalize on the potential of investment in "pure" remote sensing technology development.

In sub-group discussion, I "sensed" this issue has little importance, and even if important, its addressing involves minimal scientific merits...I disagree.

2. A fundamental issue that was not completely resolved was "how far down the data flow" remote sensing technology reaches. I "sensed" that the consensus of this workshop's participants was that R.S. stopped at the production of accurate map products (new ways to generate traditional spatial information about physical coverings of the earth). The recognition that R.S. products are one of G.I.S. inputs was recognized; however, this appears to be the point of the "passing the baton on the technology development team."

My minority opinion is that R.S. technology reaches through GIS all the way to development of generalized map analysis "tools." We have this responsibility for two reasons: 1. We are the experts in processing spatial data that is on digital form; and 2. We need to insure the maximum usefulness of our "products." -- Historic Perspective: 1950's, P.I. vs. Multispectral; 1960's imaging vs. non-imaging; 1970's human vs. digital; 1980's all-of-the-above vs. GIS; 1990's spatial information librarying vs. user modeling.

Generalization: The technology has progressed from user-driven (1940's) to technician driven systems (1980's). A real opportunity for the 1990's is to integrate R.S. technology into the decision process (i.e., return the technology to a user-driven environment).

Discussion Items for Section 4:

We are at a position in R.S. technology development similar to that of pattern recognition applications in the 1960's. We need to develop the theory, procedures, and instructional curricula for the integration of spatial information info decision-making processes.

4. Integration of R.S. products into decision-making processes
   * Fundamental Theory/Procedures
     Data Structures
       + "roster" - "polygon" conversion
       + other structures (e.g. Lucas' Hexagon "cells" based on General Balanced Ternary (GBT) Numbering Scheme)
     Analysis techniques
       + Mathematical structure of processing primitives
       + Algorithms for characterizing coincidence and juxtapositioning interrelationships

Encoding/Display support systems (Hardware/Software)
* Accuracy Assessment
R.S. Classifications
Tracking errors introduced in GIS Models
* Academic Curricula Development
University (faculty training; equipment support)
User Community (training)

Current Situations: Remote Sensing technology has matured to operational applications in many fields. Continued refinement of this technology is needed to improve the accuracy and breadth of information provided. The utility of these data has priorly been in better (or more timely) descriptions of physical phenomena.

Potential: To achieve the potential of remote sensing technology the information provided must be more fully integrated into the decision-making process. The research and eventually the information provided should be expanded to incorporate and - user needs.

Research Recommendations:

* Encourage research in processing techniques for analysis of spatial data for other than spectral classification (e.g., expression of forest classification map in terms of relative access and availability as a better estimator of effective supply).

* Support education equipment and program development grants to establish a technical base for computer - analysis of mapped information. These programs should be direct to both technicians and woers.

Robert M. Haralick

What are algorithms to accomplish: spatial reasoning using remote sensing imaging in conjunction with other kinds of spatial information?

Remote sensing has been dominated by point processing algorithms in order to determine the surface cover classes or the physical parameter of the material interacting with EM energy. To a large extent this observation process is not invertible on a point by point basis. To a large extent the parameters of interest, in fact, are not point parameters but parameters which are over areas or parameters which describe arrangements of shapes. To do the kind of interpretation people are able to do requires algorithms which utilize physical models and requires the use of spatial reasoning from one part of the image to another in order to reduce uncertainty about what is going on at the surface.

The kinds of algorithms numbered are related to the kinds of things now going on in image understanding and expert systems. However, the nature of the remote sensing scene understanding and description problem will require more than "if then" rules in the usual expert system because the spatial organization will dominate the nature of the understanding processing. It will also require more than the kinds of processing that people do in geographic information systems. These algorithms will make more precise the kinds of understanding that the disciplines of geography and geology have of surface phenomena by specifying some of their talent in terms of algorithms.

Warren A. Hovis

Maintenance of communication between developer of sensor technology e.g. those who write the specifications is essential. Development of sensors and their components is, from a practical point of view, outside of the mission of NSF. What is needed is intelligent customers who can determine the most desirable characteristics of a remote sensing device, articulate those needs to those who must design and build them and build them and understand enough about how sensors operate so that they can negotiate the necessary compromises between desired performance and that which can be accomplished. Some knowledge of the factors inherent in such compromises should be instilled in the "educated customer". Meetings of the participants across the spectrum of reasonable intervals are desirable to avoid surprises, wasted development, etc.

Robert E. McIntosh

NSF should support sensor development when it is clear that instruments will result that have image remote sensing capabilities. Modest programs can be most useful in advancing important new measurement concepts. Existing microwave remote sensing data using 10-15 year old technology suggests that a new generation of instruments should be developed having greater resolution, stability and sensitivity. The development of innovative instruments should be in the context of modern data acquisition and processing techniques and should be justified by important geophysical applications instruments offering multiple sensing capabilities: e.g. frequency diversity, phase and polarization information, should be favored in order to increase information extraction capabilities.

NSF should also favor supporting projects where experimental data is compared to theoretical models. Models or measurements alone have limited value. Those models developed from basic physical principles should be especially encouraged.

James Smith

I'm thinking of three levels of investigation with the following example titles.

Specific

1. A conceptual design of the application of a laser profilometer system for estimating tree crown structure characteristics.

More General Theoretical

2. The application of monte carlo view factor calculations to multidimensional thermal radiance predictions for nature terrain media (e.g. forest canopies)

More General General

3. Here I don't have a specific title (yet) but am intrigued by Haralick's context ideas to constraining the model inversion problem (usually developed on a point basis).

General Comments.

Graduate education
Advantages of uncurstrained basic studies
Fostering of some small cross discipline studies

James C. Tilton

Under heuristic methods we discussed three different types of heuristic methods (we assumed physical models are sometimes drawn upon in developing heuristic methods). Computer assisted analysis was thought of as primarily elaborating and making more convenient to use already existing analysis techniques (incorporating new techniques as they are developed). In this area we were thinking of using the computer more and more for book keeping tasks and for reformating data for the convenience of the analyst. We did not feel that this area should be funded significantly by NSF because, although it is important (especially in the near term), we felt commercial concerns can and are starting to develop this area for profit.

With automated processing techniques we were talking about the development of information extraction techniques that exploit the special talents of computers, and don't really rely upon an analyst's. In emulating an analyst we were talking about getting a computer to do analysis tasks humans do well (usually on smaller scale images than a computer could handle), in ways that don't necessarily imitate an analyst, but rather do emulate an analyst's decision process. Both areas could use artifical intelligence techniques, but it is perhaps only appropriate to talk about expert systems in emulating an analyst. Both of these areas would be very appropriate for NSF to fund projects in.

Under theoretical methods, we discussed various items where the analysis was based directly on theoretical analysis rather than ad hoc or heuristic methods. In particular, we mentioned "spatial reasoning" and "computational geometry". Optimal algorithms refers to approaches that can be theoretically proven to be optimal for a particular analysis problem. NSF funding would be very appropriate in all of these areas.

Under implementation problems, we noted that certain algorithms may suggest certain computer architecture as optimal in terms of efficient processing using a particular algorithm. Also, certain architecture developed elsewhere may suggest certain analysis that would not otherwise be considered. Bob Haralick raised the idea of algorithms suggesting computer architectures, but did not think that computer architectures suggesting computer algorithms was a useful research area. Others, including myself, support the view that both aspects are equally significant. I believe the majority felt NSF funding is appropriate in both areas. Possibly this area might have a medium priority rather a high priority for NSF funding. (The independent development of new computer architectures by others would, of course, be funded elsewhere; but the development of algorithms to exploit the new architecture would be funded as a remote sensing project.)