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Support for Global Science: Remote Sensing's Challenge

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Abstract

Remote sensing today uses a wide variety of techniques and methods. Resulting data are analyzed by man and machine, using both analog and digital technology. The newest and most important initiatives in the U.S. civilian space program currently revolve around the Space Station complex, which includes the core station as well as co-orbiting and polar satellite platforms. This proposed suite of platforms and support systems offers a unique potential for facilitating long term, multi-disciplinary scientific investigations on a truly global scale.

Unlike previous generations of satellites, designed for relatively limited constituencies (e.g., Landsat for the land scientist and Seasat for the oceanographic community), Space Station offers the potential to provide an integrated source of information which recognizes the scientific interest in investigating the dynamic coupling between the oceans, land surface, and atmosphere.

Earth scientists already face problems that are truly global in extent. Problems such as the global carbon balance and regional deforestation and desertification require new approaches, which combine multi-disciplinary, multi-national teams of researchers, employing advanced technologies to produce a type, quantity, and quality of data not previously available.

The challenge before the international scientific community is to continue to develop both the infrastructure and expertise to, on the one hand, develop the science and technology of remote sensing, while on the other hand, develop an integrated understanding of our global life support system, and work toward a quantitative science of the biosphere.

Introduction

The newest and most important initiatives in the U.S. civilian space program currently revolve around the Space Station complex. The Space Station complex includes a space station, and its associated co-orbiting and polar satellite platforms. This proposed suite of platforms and support systems offers a unique potential for facilitating long term, multi-disciplinary scientific investigations on a truly global scale.

Basically, the man-tended systems which are proposed for the various platforms have the capability of providing a wide range of data from both operational and research sensors. The large volumes of multispectral, multitemporal data from these systems supported by efficient and effective data systems provide the potential for data continuity which has, to a large degree, been lacking from sensor systems operating on independent free flying platforms. The challenge to the remote sensing community is, in essence, two-fold. The first challenge is to get ready to handle the large volumes of data which will become available in the 1990 time frame. The second challenge to the remote sensing community is to bring the science and technology we are developing to broader constituency, in the service of what we call *global science*: or as discussed by Botkin et al. (1984), "The Science of the Biosphere". The biosphere is the large scale planetary system that includes and sustains life.

From the perspective of scientists studying the earth's surface, the most important component of the Space Station complex is the Earth Observing System (EOS) (NASA, 1984a; NASA, 1984b). EOS, based on the current design concept, has both active and passive earth surface imaging sensor systems as well as atmospheric sounding systems (Table 1). EOS is an evolutionary step in our capabilities for remote sensing of the earth, and

TABLE 1 EOS SURFACE IMAGING AND SOUNDING (Taken from NASA 1984a)

INSTRUMENT	MEASUREMENT	SPATIAL RESOLUTION	COVERAGE
	SISP-Surface Imaging & Sounding Package		
1. Moderate Resolution Imaging Spectrometer (MODIS)	Surface and Cloud imaging visible and infrared .4 nm - 2.2 nm, 3-5 μm, 8-14 μm resolution varying from 10 nm to .5 μm.	1 km x 1 km pixels (4 km x 4 km open ocean)	global, every 2 days during daytime plus IR nightime
2. High Resolution Imaging	Surface Imaging .4-2.2 nm. 10-20 nm spectral resolution	30 m x 30 m pixels	pointable to specific targets, 50 km swath width
3. High Resolution Multifrequency Microwave Radiometer (HMMR)	1-94 GHz passive microwave images in several bands	1 km at 36.5 GHz	global, every 2 days
4. Lidar Atmospheric Sounder and Altimeter (LASA)	Visible and near infrared laser backscattering to measure atmospheric water vapor, surface topography, atmospheric scattering properties	verticle resolution of 1 km, surface topography to 3 m verticle resolution every 3 km over land	global, daily atmospheric sounding; continental topography total in 5 years
	SAM-Sensing with Active Microwaves		
5. Synthetic Aperture Radar (SAR)	L, C, and X-Band Radar images of land, ocean, and ice surfaces at multiple incidence angles.	30 m x 30 m pixels	200 km swath width daily coverage in regions of shifting sea ice
6. Radar Altimeter	Surface topography of oceans and ice, significant wave height	10 cm in elevation over oceans	global with precisely repeating ground tracks every 10 days
7. Scatterometer	Sea surface wind stress to 1 m/s, 10° in direction Ku band radar	one sample at least every 50 km	global, every 2 days

may provide the earth, ocean, and atmospheric science communities with data to support integrated investigations among disciplines and scientists from many nations on an unprecedented scale. Unlike the previous generation of satellites, designed for relatively limited constituencies (e.g., Landsat for the land scientist and Seasat for the oceanographic community), EOS has the potential to provide an integrated source of information which recognizes the scientific interest in investigating the dynamic coupling between the oceans, land surface, and atmosphere.

In the same way that EOS represents an evolution in earthward-looking satellite technology, we believe the scientific objectives which EOS may help to accomplish can produce an evolutionary improvement in our understanding of our planet. Traditional branches of the earth sciences have been limited in scope to modest areas, and to the relatively narrow ranges of biophysical, geochemical and socioeconomic processes by the extent technology to measure, map, monitor, and model those processes. It is our hope and indeed appears to be the hope of the United States (U.S.) National Aeronautics and Space Administration (NASA) that EOS will foster and expand collaboration between scientific disciplines, continuing recent trends within the remote sensing community toward interdisciplinary science on an international scale.

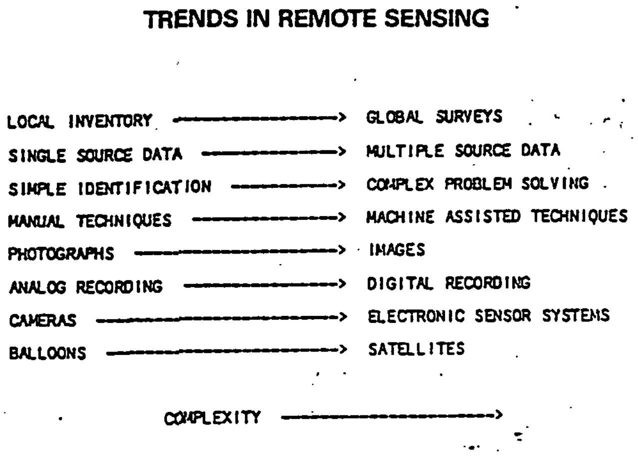
Historical Perspective

The history of science shows a general trend towards specialization: individuals developing greater expertise in increasingly narrow fields. A portion of this specialization has been enhanced by technological developments. The microscope expanded our horizons inward; early optical microscopes evolved into today's computer-controlled electron microscopes and microprobes. The telescope expanded our horizons outward; technology has brought us to a time of electronically controlled active mirror telescopes and radio telescopes to probe the distant reaches of the universe. Early timepieces permitted navigation over the high seas and a time of rapid developments in the science of cartography. Today's geographers and map makers use the tools of high technology, including both advanced digital computers and satellites, both for finding and then locating and plotting objects on the earth's surface.

Over the last decade, however, society has become more aware of problems which are fundamentally interdisciplinary: the greenhouse effect, regional deforestation, and groundwater pollution are only a few examples. An understanding of the greenhouse effect requires not only knowledge of the effect of the atmosphere's composition on radiative heat balance, but also atmospheric circulation, land/atmosphere interactions, ocean/atmosphere interactions, as well as biogeochemical cycles on the land, in the air, and in the ocean. The EOS program as presently constituted represents both a means to provide the data needed for such complex, large-area problems and an attempt to develop the infrastructure needed to address these problems.

The history of remote sensing mirrors those trends which have occurred in science and technology at large (Figure 1). The tethered ballons of the 1850's and 1860's were the first remote sensing platforms. Balloons evolved to the aircraft of the early 1900's, and then to the first satellite platforms which became available in the 1960's. The Space Station currently being planned for the 1990's includes a permanent manned presence in space. This station complex with its manned core, co-orbiting and polar platforms represents a major step in our observational potential. The earliest sensors were the human eye, and the earliest recording devices tablet and scribes; panchromatic films developed in the 1830's lead to the color films of the 1920's and these evolved into the electro-optical real synthetic aperature sensors of the 1950's and 1960's. Until the 1960's, data produced by remote sensor systems were analyzed using analog techniques. In the 1960's and continuing through to the present, the digital computer has become an increasingly important analytic tool.

Figure 1. Simplified diagram of trends which have occurred in remote sensing over the past 150 years.



Today's remote sensing practice uses virtually every technique developed in the past 100 years. Balloons, aircraft, and satellites all carry senors ranging from cameras to electronic scanners and sounders, and synthetic aperature radars using virtually all of the electromagnetic spectrum. Resulting data are analyzed by man and machine, using both analog and digital techniques sharing portions of the tasks . In a modern remote sensing laboratory, the light table and stereo viewer are found next to the computer terminal – and the modern student of remote sensing science recognizes the potential of each.

The field of statistics developed in the 17th and 18th centuries provided science with a vital tool for understanding natural processes. In the 1920's and 1930's, the development of sampling theory furthered applications of statistics. These developments, along with computer technology in the 1950's and 1960's, provided the remote sensing community with necessary tools, for hypothesis testing and the design of field work to both verify and provide confidence limits on the products of our analyses. Further, statistics provides the theoretical background to move from simple identification of single source data to complex problem solving using multiple data sources. The distinction between data and information is elusive, and we realize that one scientist's data may be another's information. Within the context of the science of the biosphere, vigorous application of sampling theory and statistical accuracy verification are required for at least two reasons. First, we are beginning to unambiguously demonstrate that existing maps are woefully inadequate to the task of providing baseline information for monitoring and modeling those dynamic processes that help to sustain life on the Earth (Botkin et al. 1984; Mann, 1985). Second, the multidisciplinary work we anticipate in the future must be rigorously based on ground truth and accuracy verification.

Applications of multisource data are most important in modern remote sensing, and we often use the phrase "information system" to describe our concept (Estes, 1984). An information system encompasses the entire flow of data, from sensor systems, through calibration and processing, through dissemination of derived information, to some end user and a decision process (see Figure 2). An important element of a new direction in remote sensing research is found in the recommendations of the EOS Science and Mission Requirements Working Group: "The Earth Observing System should be established as an information system..." (NASA, 1984a). The statement recognizes that if EOS is viewed simply as a senor platform, without considering the processing and distribution of resulting data and information to a user community the potential of EOS will never be realized.

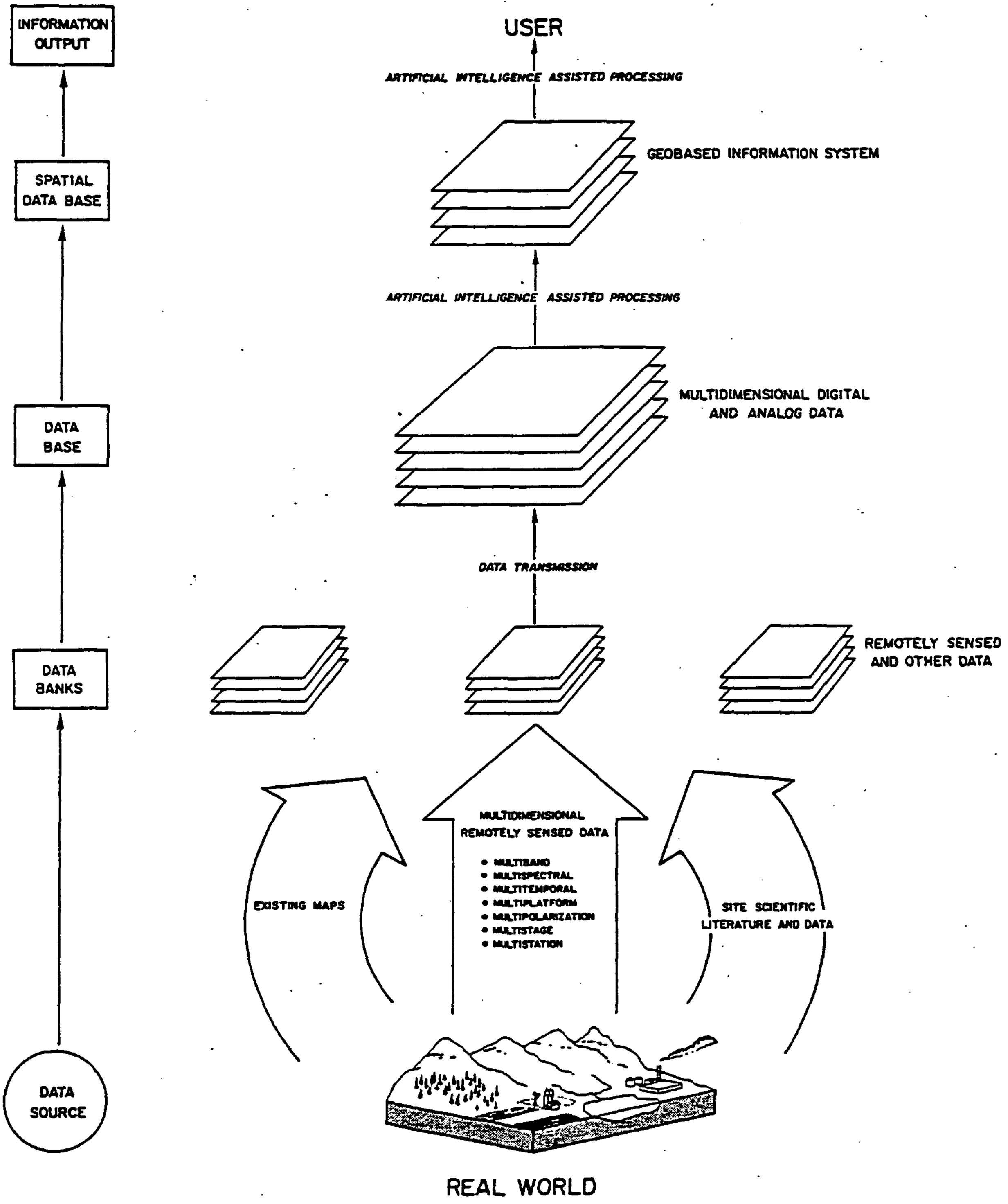


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Figure 2. The variety of data types and levels of data sources from which users may acquire data for a remote sensing analysis task.

Current Trends

Naisbitt in his book *Megatrends* (1984) discusses the new directions which he believes are transforming modem man and the planet on which we all live. Several of these megatrends are directly relevant to the challenges to be met by the remote sensing community as we move to take full advantage of evolving remote sensing and related information science technology. *Megatrends* discussed by Naisbitt include: the move from an industrial society towards an information society; from force technology to high technology with high touch (i.e. counter-balancing human response); short term to long term; centralized to decentralized; hierarchies to networking; either/or to multiple options; and, finally, with apologies to Mr. Naisbitt for not using "national economy to world economy", we are moving from addressing local and regional science issues to topics of global concern.

The first megatrend discussed by Naisbitt (1984) is what he calls our global move from an industrial to an information society. In Naisbitt's own words, "None (of these megatrends) is more subtle, yet more explosive than the megashift from an industrial to an information society". This information society, says Naisbitt, had its beginning in 1956 and 1957. It is interesting to note here that this is the time frame for the launch of Sputnik and about the time we began to move from using the term aerial photographic interpretation to the term remote sensing.

Remote sensing is an information generating technology. One only has to examine the Applications volume of the recent *Manual of Remote Sensing* (Estes and Thorley, 1983) to find eleven chapters and over eleven hundred pages, written by over one hundred and fifty authors, to see the tremendous variety of information being generated from this technology. However, many of us deeply involved in this field feel frustrated. We feel that if we could only find our data more efficiently, manage it better, and use it in a better fashion we could do so much more. Better information systems are needed which link scientists at institutions not only with the U.S. but around the globe.

In remote sensing we are also moving, albeit in this area most slowly, from forced technology to high tech with high touch. To see that remote sensing is high tech we need only to look again to the second edition of the *Manual of Remote Sensing* (Simonett and Ulaby, 1983).Yet in the development of this technology users have not always been well served. Often, we as scientists, have been presented with systems by the engineering community and asked "What can you do with this?" While this has changed somewhat in recent years, science and applications data users must be brought into the mission planning process at the earliest possible moment. There is still a nagging suspicion on the part of many in the remote sensing community that our voices are not always heard.

It is obvious that we, as scientists interested in our own data needs, may ask for too much. However, we hope that NASA, ESA, and other agencies involved in the forefront of remote sensing will listen to a community which recognizes the information potential of remote sensing, yet is leery of the impacts of commercialization on our long term science access to satellite data – a community fearful that space stations and its associated systems, even including EOS, will further erode what is currently a bare minimum and patently inadequate funding for basic and applied remote sensing oriented research. We have the high tech, yes, but what is needed, as Naisbitt says, is more high touch, a counter-balancing human response that recognized the needs and concerns of the scientists and applications of remotely sensed data. Our goal is to do the best science possible (Estep, 1968), to employ the fruits of our marvelous technology to provide an adequate standard of living for mankind.

In a more subtle way within this high tech/high touch trend, we also see an increase in the use of techniques from artificial intelligence as a trend towards high touch. Particularly, work in the area of expert systems and natural languages is showing potential for making complex processing of remotely sensed data easier and more understandable for science and application users alike. These techniques, if properly applied, show potential for allowing the less-trained individual to take full advantage of the range of services offered by a system such as EOS. Research and development in this whole area is, and should be, directed at letting scientists and users act more like scientists and users than librarians, communications specialists, computer scientists, and so on.

Analogous to Naisbitt's short term/long term are the trends we have seen in the shifts from applied to basic research within NASA since the launch of Landsat 1. Prior to 1972, many researchers in the U.S. and around the world in the field of remote sensing were doing fundamental work on the digital processing of aircraft multispectral scanner data. Overnight, Landsat 1 provided a large volume of data in digital format which was not a research, but an operational satellite. Instead of building a solid research foundation, we in the U.S. moved directly towards applications with a new sensor which had an inadequate information system, and basic research foundation to support of large number of applications.

In recent years (1979-1980), we have seen a shift within NASA back to a more basic research emphasis, looking at the use of remote sensing concerning problems requiring long range research. The recent Global Biology/Global Habitability and the EOS science and mission requirements documents produced by NASA make this trend clear (NASA 1983a, NASA 1983b, NASA 1984a, NASA 1984b). This trend may not be as clear in NASA's actions in the information sciences. The current data pilots funded by NASA code EI are aimed at employing existing technologies to improve access to processing of, and interaction with, remote sensing data and scientists using that data. We believe that this is proper in this case. There is a very large and compelling need here to do this. Yet, NASA must not lose sight of the need for basic research in the information sciences as well. If we are to gain the maximum benefit from new EOS senor systems (such as the multifrequency, multiple look angle Synthetic Aperature Radar and the High Resolution Imaging Spectrometer), let alone combine data from these space-based sensors with other ancillary data types, a great deal of fundamental thought and work is needed.

The next two trends are centralized to decentralized, and hierarchies to distributed systems. These trends also illustrate a change from single-investigation research to multi-disciplinary, multi-institutional research as expressed in the EOS Science and Mission Requirements documents (NASA 1984a, NASA 1984b). In the past, only a few countries and research centers. (principally federal laboratories and a few universities) had the computing capability to acquire and deal effectively with satellite data. We take hierarchies in Naisbitt's sense to be individual organizations geared toward working independently, in contrast to networking which attempts to facilitate the interaction of these organizations. What we have in remote sensing today are hierarchies, where central facilities distribute data and processing knowledge to the community. Today countries and institutions in all parts of the world have acquisition and processing capabilities. This presents a new protocol, associated with the idea of networks as opposed to hierarchies. What is required are more efficient and effective networks for the exchange of data on a global scale. Data/Information Systems which facilitate communication among scientists around the world are working to improve our understanding of biospheric processes.

The megashift from "either/or" to "multiple option" can be related to the use of geographic information systems which facilitates the multi-options, we have in remote sensing today. Early on in machine assisted processing of remotely sensed data, there was a push to obtain all information on a given problem from a single multispectral satellite image alone. When researchers began to realize that the information in the spatial and spectral domains represented in a single image was insufficient to many tasks, we began to explore the multi-temporal aspects of the data. Once we exhausted this possibility, we began to explore the potential of incorporating digital terrain data. Later we digitized soils, geologic and landuse maps. Crop phenologies were plotted as trajectories and processed. Prior probabilities and logic were employed to assess the nature and magnitude of change in a given area.

Many researchers now employ a wide variety of spatially-referenced data in remote sensing research. The synergism between geographic information system technology and remote sensing truly enhances the potential of each. For remote sensing data to be most useful they must typically be combined with other data types. In contrast, the quality of geographic information systems depends on the currency of the data they contain. Remote sensing can update GIS data planes while GIS can provide for the efficient use of the ancillary data required by remote sensing (Estes, 1984).

Finally, in the use of remote sensing, we are moving toward addressing issues which are truly global in nature. That is, we now have the potential to collect consistent global-scale data sets from which information may be derived and whose accuracy is verifiable. Past estimates of important global parameters (such as vegetation types, primary productivity, and biomass) have been difficult to develop and virtually impossible to verify. EOS can be one of the keys to unlocking global science. Yet, to continue this metaphor, it will be *information systems* which will allow us to turn this key in the lock. Improved information systems will facilitate our ability to conduct global research in an effective manner.

Analytic Forms and Objectives

This is particularly important as we look to the types of analyses that will be conducted using the EOS information system. Examples of these analyses will generally take one of four explanatory forms and be oriented toward at least three objects which will be discussed in some detail here. Explanatory forms include: (1) morphometric analysis, (2) cause-and effect analysis, (3) temporal analysis, and (4) functional and ecological systems analysis (Estes, Jensen and Simonett, 1980). Objectives include: (1) inventory, (2) mapping, (3) monitoring, and (4) modeling (Estes, 1985).

Morphometric Analysis

Scientific studies typically require measurement to determine the morphology of phenomena, i.e., their form and structure. Measured properties of phenomena may be generally classified as physical, spatial (geographical), or temporal properties. It is important to obtain quantitative information concerning these parameters in addition to descriptive evaluation.

Scientific investigations may require data ranging from simple in site observations where the spatial properties are not important, to complex analyses where the properties of phenomena are most significant when viewed in relation to their spatial association with other phenomena. Field investigations are typically costly and site specific, providing only point observations that must be interpolated to yield a geographical surface. Remote sensing, however, can provide both point (per picture element)and areal physical property information. Remote sensing can play an important role in providing information on a number of biophysical properties, such as geometry (size, shape, arrangement, etc.), color or visual appearance, temperature, dielectric nature, moisture content, and organic and inorganic composition (Jensen, 1983).

A fundamental characteristic of remote sensing when applied to morphometric analysis is that a given scale of observation may provide specific types of categorical information by itself, and it can be used as a method of stratifying an area for subsequent analysis.

Cause-and-Effect Analysis

Man has always examined the processes acting on his surroundings and attempted rational explanations of the causes. The synoptic view has important implications for regional studies which attempt to identify cause-and-effect relationships. The establishment of cause-and-effect relationships is important to researchers in all branches of science. Increasing our ability to perceive effects which may be beyond direct visual experience can provide insights which may lead to improved understanding of environmental phenomena and processes.

EOS and remote sensing in general offers scientists the capability to extend our understanding of effects which were until now beyond the limits of our perception and effective measurement. This may include recording a given wavelength of energy outside the visible spectrum and/or assume a viewing perspective for a sufficient period of time (e.g. geostationary satellite) to adequately monitor phenomena. For example, thermal infrared scanners can record temperature differences in a river to pinpoint the location and provide a spatial perspective on a thermal plume undetectable by the unaided eye (Estes, et al, 1983). Similarly, the reflective near infrared has been employed to detect biophysical stress (i.e., effect) before the cause (e.g., loss of moisture from pathogens) is detectable in the visible spectrum (Jensen, 1983).

Temporal Modes of Explanation

While in many scientific studies spatial variations are prime concern we must also consider the temporal domain. EOS sensor system for surface imaging and sounding show a variety of temporal resolutions consistent with science needs (see Table 1). A concern with time in science stems from two principal considerations:

(a) Explanation of observed phenomena typically involve an analysis of processes and sequences which occur through time.

(b) The rates of change for a given phenomenon constitute an important characteristic.

Change in many scientific studies is synonymous with process and sequence. To be able to identify and monitor change accurately and consistently within a spatial framework is important. The ability to view objects and/or phenomena in their spatial context through time in a consistent manner is an important contribution of remote sensing to global science. Inconsistent data plague temporal studies. EOS data will be our internally consistent, longitudinal (i.e., temporal) data set.

The acquisition of a single datum or multi-temporal data depends upon the application. If the study is primarily concerned with relatively static phenomena (e.g., soils, slopes, rock types), single or widely spaced observations may be sufficient. If, on the other hand, dynamic phenomena (e.g., runoff, flooding, crop growth, moisture response) are involved, the temporal resolution of EOS provide data to meet a variety of science requirements. For an example see Table 2. In addition, by interogating an interaction matrix between static and dynamic phenomena developed from remote sensing supplied data, much detailed information concerning the functioning of both static and dynamic elements present in a given landscape can be achieved (Estes, Jensen and Simonett, 1980).

Functional and Ecological Systems Analysis

Data must be transformed into useable information in order to understand a process or to make a decision. While researchers often require spatially accurate data for both micro- and macroscale phenomena, efficient or accurate methods commonly do not exist for collecting these data. Remote sensing systems offer the means to acquire such data, and are beginning to be applied to systems analysis at both ends of the spatial continuum. Researchers at the University of California, Santa Barbara (UCSB), have been working with NASA personnel to understand the relationship between reflectance from major species in the North American Boreal Forest as well as leaf area index and biomass. The research involves the gathering of detailed field data and correlating the information derived with data acquired using helicopters, aircraft, and satellites.

In addition to these studies, UCSB and NASA researchers have been examining the potential of using advanced very high resolution radiometer (AVHRR) and Landsat imagery to map within known accuracy limits the areal extent and spatial distributions of major forests types in the North American Boreal Forest (see Figure 3). The combination of these research projects is directed at improving our scientific understanding of the cycling of carbon and other elemental materials (Atjay et al, 1979; and NASA, 1983a). In addition, scientists with remote sensing backgrounds are examining the information gained by the application of models to a number of physical processes and cultural phenomena (e.g., crop inventories, monitoring snowmelt runoff, developing models for monitoring urban expansion, and energy consumption). EOS will greatly faciliate these types of studies.

The use of remotely sensed data as input to numerical models together is complex to implement, but attractive

TABLE 2 SAMPLE SCIENCE OBSERVATIONAL NEEDS (Taken from NASA 1984a)

PARAMETER	APPLICATION	ACCURACY DESIRED	ACCURACY REQUIRED	APPROACH	SPATIAL RES.	OBSERVATION FREQUENCY	SPECTRAL RES.
Soil Features							
o Moisture	Hydrologic & geochemical cycles	5 moisture levels	5 moisture levels				
o Surface		5%	10%	Microwave Radiometer	1-10 km	2 day	20 cm ± 1 cm
o Root Zone		5%	10%	Model	30-1000 m	1 week	20 cm ± 1 cm
o Types-Areal Extent (peat, wet lands)	Geochemical cycles Agricultural & Forestry	10%	10%	Visible/SAR	30 m	annual	20 nm/50 nm
o Texture-Color	Agriculture & Forestry	10%	10%	Visible/SAR	30 m	annual	20 nm/50 nm
o Erosion	Geochemical cycles	10%	10%	Visible/SAR	30 m	annual	20 nm/50 nm
o Elemental storage	Geochemical cycles						
o Carbon		10%	10%	Visible/SAR	30 m	monthly	20 nm/50 nm
o Nitrogen		10%	10%	Visible/SAR	30 m	monthly	20 nm/50 nm
Vegetation							
o Identification	Hydrologic cycle, biomass distributions & change,	1%	5%	Visible, Near IR, Thermal IR	1 km	7 day	10-20 nm
o Areal Extent	primary production, plant productivity, respiration,	1%	10%	Visible, Near IR, Thermal IR	30 m	30 day	30 nm
o Condition (stress, morphology, phytomass)	nutrient cycling, trace gas, source sinks, vegetation-climate interaction, microclimate	10%	15%	Visible, Near IR Thermal IR, SAR	30 m	3 day	10-20nm
o Leaf area index canopy structure and density		10%	20%	Visible, Near IR, Thermal IR, SAR	30 m	3 days	50 nm

in several ways. First, remote sensing data are inherently distributed (i.e., spatially disaggregated). As such they are incompatible with many conventional models of environmental processes wherein values for a given area are "lumped" in some fashion or assigned to a specific node. Typically, these models do not readily accommodate remote sensing inputs.

Second, distributed models (both because of their greater spatial specificity and because they often are more of the deterministic than of the nodal or index type) may offer the potential of greater forecasting power under extreme conditions. Finally, the combination of remote sensing and modeling within a geographic information system framework (where inputs are organized employing geographic coordinates) has special appeal because it appears that each needs the other to realize their maximum contribution. Thus remote sensing may play an integral part in functional and ecological systems analyses wherein it may act as a key to the interfacing of biophysical, geochemical, social, and economic data for effective modeling purposes.

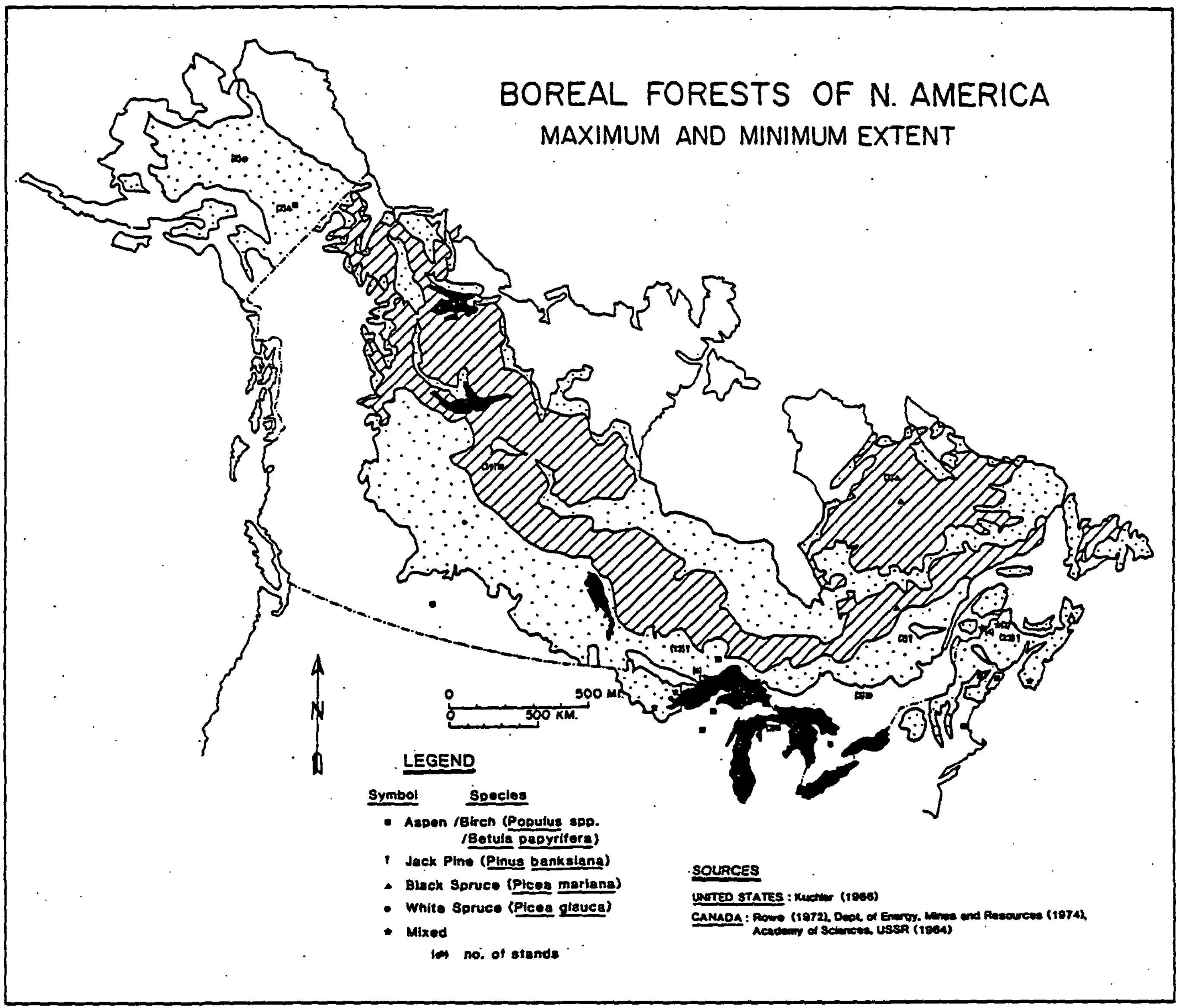

Figure 3. The variation in areal extent of the North American Boreal Forest derived from "reliable" conventional sources. Minimum extent common to all sources is in hatched pattern. Maximum extent from sources used is represented by dot pattern.

Inventory

While the modes of explanation discussed above are examples of the scientific analyses which will be conducted employing EOS system, the objective of these studies will be to achieve an improved knowledge of those biochemical, geophysical, and socioeconomic processes that affect life on this planet. EOS can provide significant help in this area. EOS will improve our ability to inventory and map critical resources, facilitate monitoring of critical resources and processes occurring over both large and small areas of the globe, and improve the accuracy of our models of the complex processes which impact life on this planet.

Mapping

Most users involved in geographic analyses want to see a map of information relevant to their application. Basemaps today are largely derived using photogrammetric techniques. It is in the area of thematic mapping (e.g., land cover, hydrology, soils, etc.) that considerable research is occurring on the use of remotely sensed data. Thematic mapping is an important component of any land resources investigation (Simonett, 1976). The Federal Mapping Task Force identifies Mapping Charting, and Geodesy (MC&G) tasks as being:

- Land Surveys (point positioning for geodesy, cadaster, engineering);

- * Land Mapping (planimetric, topographic, thematic);
- * Marine Mapping (nautical chart, bathymetry, floating aid, hazard) (Donelson, 1973).

The above list could serve as general cartographic requirements for most countries of the world. Currently, such tasks are carried out within the United States' national mapping programs primarily by the Defense Mapping Agency, the U.S. Geological Survey, and the National Oceanic and Atmospheric Administration. The U.S. federal MC&G task force, however, cannot meet the current requirements for maps, charts, and geodetic information. For example, the U.S. Geological Survey can satisfy only about 16 percent of the first priority needs for new mapping and 39 percent for revision of outdated maps (Donelson, 1973).

The ability to produce thematic maps from remotely sensed data is directly related to our ability to extract data on the classes of thematic data of interest to a given user employing either manual or machine-assisted processing techniques. It is important to note that most maps produced for operational applications of a geographic nature are derived from visual image analysis techniques. Researchers in many disciplines are working to improve machine-assisted classification accuracies (Rosenfeld, et al, 1981; Rosenfeld, 1982; and Estes et al, 1983). This task, however, is formidable and there has been a general overselling of remote sensing's ability to provide accurate thematic data in a rapid fashion. This overselling has made it difficult at times to obtain funds required to gain an in-depth understanding of the steps needed to improve existing thematic mapping capabilities.

Monitoring

The ability to detect changes in land cover patterns or biophysical characteristics is central to our ability to use remotely sensed data for planning and management purposes (Anderson, 1977). Monitoring of agricultural crops during a growing season can lead to the prediction of regional production. Rates of change of environmental parameters are highly variable by category and location. As an example, the encroachment of urban land use onto prime agricultural land at the rural-urban fringe occurs at a much faster rate than that of the regeneration of clearcut land to forest. Thus variation in rates of change must be carefully assessed from both functional and spatial perspectives in order to provide appropriately stratified units amenable to the systematic extraction of change information.

Interest has increased in recent years in the potential of remote sensing for monitoring environmental phenomena. Recent NASA programmatic interest in Global Biology and Global Habitability and the National Academy's proposed International Geosphere Biosphere Program (IGBP) are largely predicated on the ability of remote sensing to monitor selected environmental conditions on a global scale (NASA, 1983a; NASA, 1983b; and Waldrop, 1984). These programs propose to collect information which has significant geographic applications. From research on desertification and deforestation to estimates of global elemental cycling and factors affecting climate, these programs call for monitoring and modeling research on an unprecedented scale. It is encouraging to note that these programs recognize the need for long-term research. Yet, from a reading of these and other similar documents it appears that there is a feeling that, at least within research funding agencies within the U.S., the image analysis techniques and processing, storage, and retrieval systems required to support these efforts are in place and only need to be applied. This is unfortunately not the case.

Research using Landsat data for the detection and mapping of changes in land cover have demonstrated some potential, but much more needs to be done. To date, change detection studies employing machine-assisted processing techniques have demonstrated a potential for detecting and identifying areas of certain types of environmental change (Christensen and Lachowski, 1977; Friedman, 1978; Place, 1979; and Computer Systems Corporation, 1979). They have not, however, demonstrated the capability to detect changes consistently and with field verified absolute accuracies in the 80- to 90-percent range in a variety of geographic environments (Estes, Stow and Jensen, 1982; Estes, 1985).

Modeling

An important aspect of remote sensing has been to develop models which can be driven by inputs derived from remotely sensed data. Models which employ machine-assisted processing of remotely sensed data to address specific geographic applications are still largely in the development stage. Considerable research emphasis must take place if we are to extend our understanding from the realm of systems structure into the area of systems processes and dynamics.

The ability to predict consequences of trends in environmental conditions and to assess the potential impacts of management decisions through simulations is an important step towards understanding the state and dynamics of a variety of geographic phenomena.

Remote sensing techniques have been applied to provide inputs to land capability and suitability models. Most operational usage, however, is limited to manual interpretation of aerial photographs. In many instances, acquiring and processing aerial survey data and their subsequent interpretation create the current bottleneck in the timely and effective operation of both land capability and suitability models. Land use updates typically cost 50-75 percent of the original survey costs which severely restricts their number (Anderson, 1977). Many researchers consider the potential for semi-automated digital updates of land use surveys as the major, unfulfilled promise and potential advantage of satellite remote sensing.

All land resources have inherent temporal and spatial components. It is necessary to predict both the quantity of aggregate change which is likely to occur in the future (i.e. the amount of land area likely to leave or enter a particular land cover category) and the most probable geographic location of change. The existing literature on the application of remote sensing to land cover spatial predictive modeling is very limited (Estes, Jensen and Simonett, 1980). So too is the literature on all modeling using remote sensing which documents the potential of remote sensing inputs to models on a quantitative basis (Lulla, 1981; Barker, 1983; Lulla, 1983). Research in this area must occur if the application of remotely sensed data to research on the biosphere is to achieve its true potential.

Conclusions

In conclusion, both earth science and technology development have progressed to a point where the conduct of global science appears feasible. Indeed, the earth sciences community is already faced with problems that are truly global in extent. Such problems require new approaches, which combine multi-disciplinary, multinational teams focused on these problems, employing advanced technologies which can generate a type quantity and quality of data not previously available to the scientific community. EOS and the EOS program has this potential. Yet if we are to fully employ the potential of EOS it must be done within an information systems context, linking scientists together with both required facilities and each other. Such an approach can improve the global science community's access both to data sources and processing capabilities. The science of the biosphere is a data-intensive activity and in its broadest sense EOS as an information system can provide a tool for improved understanding of our planet (NASA, 1984a).

EOS is a complex system. It is currently planned to fly on the polar orbiting platform as part of the total United States Space Station effort. The Space Station complex offers the global science community great potential, but a number of problems as well. There are still a number of unanswered questions concerning the operational and commercial uses of the sensor systems on polar platforms. What will the United States National Oceanic and Atmospheric Administration's role be? Will the commercial Landsat vendor EOSAT be a major factor in sensor decisions? These and other technical problems [e.g. the 300 megabit per second downlink limitation of the Tracking and Data Relay Satellite System (TDRSS) when the EOS Synthetic Aperature Radar (SAR) and High Resolution Imaging Radiometer (HIRIS) data rates are projected between 700 and 800 megabits per second] must be carefully weighed. International scientific and technical cooperation and the role of the European Space Agency, SPOT Image Corporation, and the Japanese Earth and Marine Observing Systems must also be evaluated.

The challenge before the international scientific community is to continue to develop both the infrastructure and expertise which will allow the EOS information system to work properly. On the one hand, we must continue to develop the science and technology of remote sensing. This includes improved communications and advanced processing techniques, to natural language interfaces and advanced scientific workstations, as well as new sensor technology. On the other hand, we must embrace the concept of global biology, and work toward a quantitative science of the biosphere. Finally, we must put more stress on accuracy assessment and the qualification of the results of our studies. For only if we do this will we truly begin to understand the nature of the only known closed life support system capable of sustaining life for more than a few decades.

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