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APPLICATIONS OF ISES FOR VEGETATION AND LAND USE

R. Gale Wilson
NASA Langley Research Center
Hampton, VA

Summary

Remote sensing relative to applications involving vegetation cover and land use is reviewed to consider the potential benefits to the Earth Observing System (Eos) of a proposed Information Sciences Experiment System (ISES). The ISES concept has been proposed as an onboard experiment and computational resource to support advanced experiments and demonstrations in the information and Earth sciences. Embedded in the concept is potential for relieving the "data glut" problem, enhancing capabilities to meet real-time needs of data users and in situ researchers, and introducing emerging technology to Eos as the technology matures. These potential benefits are examined in the context of state-of-the-art research activities in image/data processing and management.

Introduction

The capabilities and quality of remote sensing data acquisition systems continue to improve, but data acquisition technology has outpaced the technology to process, analyze, and interrelate the voluminous data sets that are produced. The complexity of the latter technology is so great that heavy reliance continues to be placed on human interpretation of data. The state-of-the-art in digital image interpretation seems to be well summarized by Hubaux (in ref. 1, p. 127):

> Remote sensing data processing is always a fight against an excess of information; in the jungle of data through which we try to find our way, we have to use an intellectual machete to chop away most information, so as to keep only that part (most often a tiny part) which is really relevant to our problem, and find the most convincing manner to present it.
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> The present trend consists in considering remote sensing data as part only of the total information needed to solve most problems, and to incorporate them in Geographical Integrated Systems (GIS). This must, of course, be done with data in their digital format, and the use of the computer will certainly grow in the coming years. But whether the role of the human interpreter is declining, and whether completely automatic procedures will be found to solve most problems, remains to be seen.

An ISES has been proposed (refs. 2 and 3) to evaluate the role of onboard (ground-station-coupled) information extraction in space flight systems. The ISES concept has been initiated as a proposed Eos onboard experimental, computational, and communications resource to support advanced experiments and demonstrations in the information and Earth sciences. Such a resource could be an important element in addressing the overall data reduction and management problem.

The purpose of this paper is to review the current operational and Eos-planned research programs relevant to two applications areas; i.e., vegetation (including forests) and land cover/use, and to relate the needs in these programs to the ISES concept. While the paper focuses on these two remote sensing applications, many of the considerations on data requirements are not limited to just these applications. The remote sensing applications are first discussed, along with data management and processing techniques. In these discussions the primary difficulties and challenges in remote sensing research are examined to place the proposed ISES concept in proper perspective. The ISES role is then projected in terms of users' specific needs, the need for in-orbit intelligent data-taking to reduce the quantity and rate requirements for downlinked data, the state-of-the-art in data processing technology, and the long-term objectives of the Eos program.

Remote Sensing Systems

This paper is primarily concerned with satellite remote sensing systems. Ground-based and airborne sensor platforms will continue in roles of providing primary data collection, as well as ancillary and reference or calibration data to complement data from satellite systems and will continue to be important in the development of new and improved satellite systems. There exists a variety of instrumentation for collecting the Earth's reflected, emitted, or scattered radiation onboard satellite platforms. The primary instruments include photographic cameras, television cameras, visible and infrared scanning (imaging) radiometers, multi-linear arrays, and microwave radiometers (ref. 4). Each of these instrumental methods is briefly reviewed in the Appendix.

Remote Sensing Applications

A number of recent introductory and comprehensive reference books is available on remote sensing principles, applications, and instrumentation (e.g., refs. 5-7). These books provide in-depth treatments for different applications, including separate discussions for forest resource assessments, agricultural applications, rangeland applications, and urban/suburban land-use analysis. Only a brief summary will be presented here for these applications, focused on characterizing the associated types of measurement and data, to assist in considering real-time or near-real-time needs of users. For purposes of the discussions here, the vegetation category includes man-cultivated regions, as well as natural grassland, shrub-covered terrain, and forests.

Vegetation

Agricultural remote sensing involving cultivated crops, natural vegetative cover, and soil, is a very complex research subject because of the dynamic and cyclic processes and the interactions of reflection, absorption, transmission, and scattering of electromagnetic radiation by vegetation canopies. Vegetative remote sensing makes use of much of the total electromagnetic spectrum; i.e., that from the short-wavelength ultraviolet, visible, near infrared, and thermal infrared, through the longer-wavelength active radar and passive microwave regions. Microwave sensing offers the advantages of atmospheric and cloud penetration, day/night operation, and all-weather operations. For many applications, data from several wavelength regions are used synergistically. Very important use is made, too, of simultaneous ancillary weather and temperature data (e.g., National Oceanic and Atmospheric Administration (NOAA) weather satellites). Both human visual photointerpretation and computer image processing and classification play important coordinated roles in the data interpretation process.

The reflectance signature of green vegetation in the visible and infrared spectral regions is determined primarily by the chlorophyll absorption bands in the visible and water absorption bands in the infrared. As a result, there are some straightforward relationships; e.g., healthy leaves have high infrared reflectance, while unhealthy leaves have lowered infrared reflectance. Similarly, wilt (moisture stress) has long been recognized through decreased reflectance in the reflective part of the infrared spectrum. Generally, though, seasonal changes or state-of-health changes in plant canopies are not very simply related to changes in leaf chlorophyll and/or moisture content, because changes are distributed over the spectrum and there are many geometrical factors to consider in addition to the leaf reflectance: leaf transmittance into the canopy layers; the three-dimensional character of the canopy substructure; presence of stems, limbs, and other non-leaf structure; characteristics of the background, such as soil and leaf clutter; solar zenith angle; atmospheric conditions; and the observation geometry (look angle, azimuth angle). Therefore, it is not surprising to encounter numerous vegetation (and background) indices and coefficients that attempt to relate some of these influences and to account for spectral changes, which may be interrelated with spatial and temporal changes. Because of these complexities, the major problem encountered in photointerpretation and imagery analysis of crops, for estimating crop acreage, yield, and stress, is to develop techniques that are both fast and accurate in field/crop mapping. The United States Department of Agriculture, particularly, has urgent needs for better and more timely information, in the form of early warning of changes affecting production and quality, and in the form of crop-production forecasts. The USDA also has high interest in land use classification, renewable resources inventories, assessment of conservation practices, and pollution detection and impact evaluation.

Radar return signals are affected by the electrical characteristics of Earth features coupled with their geometry. The complex dielectric constant of an object is a measure of its reflectivity and conductivity. At microwave wavelengths most natural (dry) materials have a relatively low dielectric constant, whereas water is about an order of magnitude greater in its value. Therefore, water in soil or vegetation enhances the radar return signal. Plant canopies in general, with inherent high water content, provide strong signals for microwave radiometric measurements. Consequently, Side-Looking Airborne Radar (SLAR) and Synthetic Aperture Radar (SAR) applications to mapping natural vegetation; e.g., forests and crops, have been useful. Other uses of particular value to undeveloped regions of the world, are the delineation of boundaries; inventory information on forests, ranges, and water supplies; flood-inundation mapping; and determination of acreages in crop distributions. Possibilities exist for large-scale crop yield estimates. Research continues on the potentially valuable use of passive microwave imaging systems to provide regional soil moisture surveys over large inaccessible areas. Soil temperature measurements are also obtainable. With microwave sensing, burning forests, swamps, and peat piles can be efficiently detected even when covered by a heavy smoke layer.

Forest classification, inventory, and management are presently done through a combination of field activities and aerial or space imagery analysis. The eventual goal is to meet managing and planning objectives through maximum use of aerial or space imagery and to minimize the amount of field work. Classification of forest types by visual interpretative techniques makes use of highly skilled and trained imagery analysts, stereogrammetry, color and color IR photography, and scanning microdensitometry, along with sets of spectrogrammetric (e.g., Landsat) reference plots from ground sampling, orthophoto maps, SLAR data, and computer-based digital image processing.

Reference 5 describes a multilevel land-use and land-cover classification system, developed by the U.S. Geological Survey, which incorporates four categories (scales) of images and/or photographs. The scales range from 1:250,000 and smaller to 1:20,000 and larger, representing 1) Landsat MSS image, 2) Landsat TM images and high-altitude aerial photographs, 3) medium-altitude aerial photographs, and 4) low-altitude aerial photographs. The coarsest levels of classification include urban or built-up areas, agriculture, rangeland, forest land, water, wetlands, barren land, tundra, and perennial snow and ice. The other levels of classification are subcategories of the more coarse levels, providing increasing details of land cover and use. Such a classification system can serve many needs in land-use planning and can accommodate the best existing techniques of both visual interpretation and digital image classification. The majority of urban applications require data collection in cycles from one to 10 years.

Reference 8 discusses the present status and future expectations regarding remote sensing technology for urban planning. Spatial resolution of civilian satellites is too coarse to provide good definition of complex urban-type scenery, because the average size of objects forming the urban landscape is usually less than satellite resolution. Consequently, a large percentage of pixels is comprised of more than one type of land cover. In addition, any one land use does not correspond to a specific spectral signature. Therefore, classification of land uses cannot be obtained directly from spectral radiometric information, but must also make use of morphological and topological data. It is not surprising, then, that for this application much reliance is still placed on visual photo-interpretation, in which dependence is not so much on spectral radiometric information as on shape, size, elevation, and the general structure of the image. The standard method for preparation of urban land-use/-cover maps in most countries is based on visual interpretation of high-resolution image data, primarily from aerial photogrammetric camera systems. Analysis of land use requires recording high-frequency, low-contrast detail with resolutions from about 0.5 to 10 m. Instantaneous fields of view better than 5 m are needed for visual interpretation. The high-resolution requirements for urban planning generally contrast with those for reconnaissance-level planning applicable to agricultural resources.

The trained interpreter relies heavily upon personal knowledge and experience, and the approach in visual interpretation is still far too complex to be completely computerized. Expert systems compete effectively only in the less intuitive tasks. The author of ref. 9 concludes, from work with image-differencing techniques, that visual interpretation of imagery is the most accurate technique for detecting urban change. At the same time, the author recognizes that at county, regional, and national scales, automated techniques are needed to provide unified records of spatial and temporal distributions of urban change. According to ref. 10 (p. 96), color IR video data, suitably digitized and processed, and superimposed with Geographic Information System (GIS) data, could provide a near-real-time update to land use/land cover types and conditions of vegetation.

Microwave instrumentation does not record in any simple way the spectral nature of urban and suburban features. Signatures are the result of complex interactions between terrain features and actively produced microwave energy. The signatures are dependent on the interrelationships among wavelength, polarization, and depression angle of the microwave beam and on the dielectric constant and surface roughness of the terrain features. Resolution requirements vary greatly with varying cultural developments.

Quick-Look and Other Operational Satellite Programs

Real-time and near-real-time data applications are highly relevant to the ultimate potential of a dedicated onboard data handling system for Eos. A Quick-Look program has been in operation with Landsat since the early 1980's (refs. 11-13). This program provides quick availability of raw or pre-processed data to users, meeting needs that would not be met if data access depended on large receiving and processing systems focused on central government agencies requiring high-volume and high-precision image products. Such users benefit from partially corrected (radiometrically and geometrically) full-resolution film or computer-compatible tape imagery. Quick-look systems are well suited for groups that have access to a receiving station and simple computer facilities for further data/image processing. The data can be viewed in image form on a display screen during the real-time pass while the raw data are stored on magnetic disks. The stored data are processed by selected enhancement and enlargement algorithms to best satisfy individual customer requirements. Photographic products based on data enhanced to individual specifications can be distributed to customers within hours of the satellite pass. The user may arrange in advance for the coverage of an area and time period to satisfy particular needs, or may choose to examine the data retrospectively.

Applications for quick-look data include natural resource surveys, analysis of land-use patterns, routine surveillance of navigation hazards, flood-damage assessments, forest fire studies, monitoring volcanic eruption damage, and crop-yield forecasts based on the variability of the weather, tillage, and seeding activities. The Quick-Look program has proved to be of much value to agencies responsible for informing the public of impending or occurring hazardous events and for reducing the impact of such events.

Although not designated as a quick-look program, the NOAA operational satellite system provides much data of high temporal resolution (refs. 14 and 15). The NOAA system was initially justified for meeting weather forecasting needs, and the meteorologist is the primary customer today, but it has many important applications in oceanography, hydrology, and agriculture. Some of the agricultural data derived from NOAA's satellite observations include precipitation measures and predictions, daily temperature extremes, canopy temperatures, insolation, and snow cover. Weather, actually, is the most important variable in determining year-to-year changes in agricultural production. The weather observations are used in numerical models that incorporate daily increments to provide estimates of soil moisture, crop yields, crop stress, crop calendars, winterkill, vegetation areal extent, and early warning of drought or freeze.

Reference 15 presents interesting observations of the U.S. Department of Agriculture's use of NOAA Advanced Very High Resolution Radiometer (AVHRR) data for monitoring and assessing crop conditions in selected countries. Before the satellite images are observed by analysts, each scene is processed to calculate vegetation indices that are averaged over pixels in geographically referenced grid cells, and the cell averages are entered into a database. But analysts make little use of this database, depending primarily on visual interpretation of computer-displayed images, weather data, and supporting crop and soil information. In the environment of limited time and personnel, visual analysis has been found satisfactory for assessing general crop conditions. However, the authors recognize additional potential dormant in the database and propose some methods of obtaining information that is not accessible through visual interpretation. Apparently, one of the fundamental problems to be dealt with is the matter of mixed pixels; i.e., pixels filled by more than one class of land cover; this matter continues to be an area of research. This problem is not completely solvable by very high resolution instrumentation, even if the large quantity of data and the data rates could be accommodated (refs. 16 and 1).

Data Management Considerations

Multitemporal and Multisensoral Data Requirements

An attempt will be made here to summarize general data handling and interpretation needs for vegetation and land-use applications of remote sensing and the current progress toward meeting those needs. Of particular value in this assessment was reference 1, which is a current treatment based on lectures of well-known specialists, representing universities and institutes in Europe and the United States.

Generally, applications of remote sensing involving vegetation or land-use classification require multitemporal and multisensoral data to obtain the maximum information from the measurements. As more advanced remote sensing systems evolve, the temporal resolution has been improved through polar-orbit configurations such as NOAA's and the planned Eos, as well as through scanning flexibility such as the forward- and backward-look capabilities of Systemé Probatoire d'Observation de la Terre (SPOT) and the planned Eos. Multi-instrument coordination and measurement, too, emphasize Eos.

For research in agriculture or forestry, the goal is often a classification algorithm, applicable to many examples of the type of scene of interest, and to future scenes that have similar characteristics. Similarly, in land-use inventory applications, classification methods are desirable. For example, it may be of interest to obtain (preferably autonomously) a map giving the land-cover distribution on a certain date. The difficulties to be overcome to achieve autonomous classification of an image can best be appreciated by considering the process of human visual image or photographic interpretation. In fact, the present trend in computer (machine) classification research is toward emulating more and more the processes of human visualization (ref. 17). The human interpreter does not recognize features and distinguish classes through pixel-by-pixel classification or by algorithmic processes. Local feature judgments are made in the context of surrounding pixels and larger units, such as fields, forest regions, water bodies, etc. In addition, human judgments are based on time history, with variations averaged in some sense over time and over spatial variety. External information, especially ground truth, is factored into the pattern recognition process. Analogously, digital classification methods are finding more success through use of supervised (ground truth use) rather than through unsupervised classification methods, and through texture and boundary evaluations, as opposed to pixel-by-pixel analyses. Statistical pattern recognition techniques that have been a focus of recent research activity have become recognized as inadequate in many respects, since it is difficult to include ancillary information in the classification procedure (ref. 17, p. 300).

Generally, for successful digital classification or recognition, a single-time image is not adequate. Often, it may be necessary to have an image of the same scene obtained by the same satellite on another date, an image from another satellite, topographical data, or ground truth data from direct observations. It is often more important for many people who make decisions to know where and when a change has taken place than to have a detailed land-cover map about an area at each of one or two times (ref. 10, p. 426). Changes in spectral reflectivity in registered, time sequential, remotely sensed images can convey more information to natural resource managers, environmental impact monitors, and urban planners than raw, enhanced, or classified images that cover the same geographic areas of interest. Dynamic areas require attention, whereas static areas do not. Then, for the multi-temporal or multi-instrument images to be useful for digital classification, the images must be precisely co-registered.

Geographic Information Systems (GIS's)

Methods and Applications.- Geographic information (integrated) systems (GIS's) are emerging as the major spatial data handling tools for solving complex natural planning problems (ref. 10, p. 270). A GIS is a computer hardware and software system designed to collect, store, retrieve, update, analyze, and display spatially referenced data. The thrust is to combine remotely sensed or directly sensed spatial data with geographical non-spatial map data. For example, the relief (magnitude and orientation of the slope) is important in environmental studies, particularly regarding problems in forestry and mountain agriculture. In many countries, good-quality, large-scale topographical maps exist, on which relief is represented by level curves or isolines. European and American cartographic institutes during the last two decades have devoted much effort to computerizing the map-making process. Digital mapping and systems built on that technology are one of the most effective methods of making massive amounts of information understandable.

Currently there is a trend towards database design of information systems. An information system must be based on a database if users expect timely answers and want to update the system as they learn about changes (ref. 18, pp. 16-17). The GIS technology has provided the vehicle for the merger of remotely sensed data with mapped data, allowing resource managers to combine both spatial and tabular data from many sources and preserve their geographic location. The various layers of data stored in the mainframe computer are registered to one another by a grid referencing system such as the Universal Transverse Mercator (UTM) system (U.S. Army, 1969). Such systems are a primary tool for many government agencies. For example, the Bureau of Land Management, to make its database more versatile, has incorporated terrain derivatives, roads, land ownership, water, land use, and other information digitized from USGS maps or from field annotation (ref. 10, pp. 404-406). The BLM resource specialists still use these primitive databases to identify areas for particular favored uses, such as firewood cutting or transplanting of endangered wildlife. Another practicable application is the wildfire attack system to deal with lightning-initiated fires in national forests. An interactive system of digital fire-related information, including spectral imagery and weather information via the Geostationary Operational Environmental Satellite, permits local attack managers to make almost instantaneous assessment of wildfire potential and critical decisions needed for appropriate action.

Present Research Status and Future Projections. Presently, most GIS databases are produced by digitizing map products. A goal of the scientific community of cartographers and remote sensing scientists is to be able to create sophisticated intelligent spatial databases, in which the user through a friendly interface can query interactively about map, terrain, or associated imagery, and obtain help in day-to-day decision-making processes. In present GIS systems it is not possible to perform complex queries that require dynamic computation of geometric and factual properties. Research on such systems, according to McKeown (ref. 19), "requires the integration of ideas and techniques from many disciplines such as computer graphics, computational geometry, database methodology, image analysis, photogrammetry, and artificial intelligence." Although automatic integration of remote sensing data with GIS's is not yet possible, since human interpretation and assistance are still necessary, AI/expert systems are expected to eventually play a significant role in the integration of remote sensing data with GIS's (e.g., see refs. 19-23). Reference 24 reports on the design of an expert system based on Landsat imagery. In that paper it is pointed out that the traditional approach to the analysis of remotely sensed imagery based on image processing techniques, such as segmentation and statistical classification, is basically limited by the lack of integration with geocoded databases and by the difficulty of handling contextual information. However, expert systems are likely over the near term, to remain largely research, or experimental systems. Prototypes based on formal AI languages will play a very important role in the future toward development of practical systems (ref. 10, p. 517). In reference 25 it is observed that problems known to require much commonsense knowledge, English-language understanding, complicated geometric/spatial models, complex causal/temporal relations, or the understanding of human intentions are not good candidates for current state-of-the-art expert systems. Such problems are seen as central to the development of practical geographic expert systems, and therefore, the need for much basic research is anticipated before practical geographic expert systems become a reality.

The digital terrain model (DTM) or digital elevation model (DEM) is an important data representation for some geographic information system applications. The importance of such a model is emphasized by the fact that high-precision image rectification for high-resolution land-use satellites such as Thematic Mapper and SPOT is possible only if a DTM is used as the master image (Dejace, in ref. 1, p. 140). In such use, the DTM becomes the primary data set, with the remotely sensed satellite data being supplementary to it. A DTM may be regarded as a data table giving the altitude above sea level of the nodes of a two-dimensional grid, generally with a square cell. The DTM is similar to a digital image and can be organized in computer memory in raster format. Construction of a DTM is a difficult process. Building a DTM either from stereo pairs of aerial photographs or from a topographical map involves specialized photogrammetric or complicated mathematical operations. Once such a model is generated, however, it is straightforward to calculate other associated models; e.g., the slope and azimuth of the maximum slope direction at every point of the grid, from which sun incidence angle, shadowing, and other phenomena may be calculated for each pixel. Possibilities such as the number of sunshine hours at each pixel corrected for incidence angle are envisioned.

There are significant problems to overcome in transforming digital map data into a DTM that can be integrated with satellite imagery. Part of the problem is the question of appropriate digital representation of the spatial geographical data. There are two distinct ways in common use for storing spatial information for computer use; i.e., "raster" format and "vector" format (Dejace, in ref. 1, pp. 136-137).

The raster format is analogous to the format in which digital images are stored. The coordinates of points are not written explicitly, but are easily retrieved for each pixel from the order in which the data are stored. Such a format is possible only when the data are organized in such a system as the nodes of a regular grid. The way in which the data are ordered in storage must be defined explicitly.

The vector format for storing data is used primarily in computer-aided cartography. A point is represented by its explicitly written spatial coordinates. A line is represented by an ordered sequence of pairs of coordinates defining points; i.e., the line is approximated by straight segments linking these points. A code is included to indicate what the line represents; e.g., a road, railroad track, or river. A surface is represented by its contour line and a code.

Both the raster and vector formats are used as intermediate data storage formats, thus creating a dilemma in the development of GIS's. Maps created by specialized hardware by using the vector format are of high cartographic quality, similar to conventional hand-drawn maps. However, algorithms for processing vector-formatted data are more complicated than those for the raster format. When there is need to compare several thematic maps or images, the raster format provides more straightforward procedures than the vector format. In addition, recently developed software and specialized hardware for image processing are directly usable with the raster format. Resource managers have to combine the analytic capabilities of the best raster systems with the superior storage handling and output capabilities of the best vector systems, and at the same time allocate attributes spatially by means of an integral database management system. Such capability for interacting many data themes, for alternate options, requires a format which can present data in different combinations, interact them repetitively, and update and correct them easily. Development of specialized software is required and must be transportable from one computer system to another.

Most geographical data must be obtained from maps, and is usually digitized manually by use of a digitizing table involving vector formatting or by a raster scanner. Neither method is straightforward, however. Manual digitizing is tedious and susceptible to human error, and is considered a bottleneck in geographical data processing. On the other hand, most geographical paper documents are not suited to raster scanning because they contain too much information requiring pre-scanning, editing, and post-scanning steps. Therefore, manual digitizing, with the human eye, brain, and hand selecting what to digitize, is often the only current practicable method of digitizing. After the digitizing of several sets of data, geometrical processing is necessary to co-register them and to properly align them with satellite digital imagery.

Potential Role for Proposed Information Sciences Experiment System (ISES)

Recent papers (refs. 2 and 3) have characterized several needs for an Eos onboard computational resource:

- To permit experiments and demonstrations in onboard information extraction, in support of both Earth science and information science technology advancement

- To provide direct-to-user data products

- To provide real-time response to events

- To operate as an interactive experiment on a non-interference basis relative to other on-board instrumentation

- To directly address the "data glut" problem

- To provide capability for growth of Eos into evolving technology without adversely affecting standardization and reliability of the operational space system

These needs are discussed further.

Quick-Look Needs for Eos

Some aspects of the ISES concept have been partially introduced into the design of the Eos (refs. 26 and 27), at least relative to the MODIS and HIRIS instrument operations and the coordination of their data outputs through the Eos Data Information System (DIS). These two instruments are designed to be complementary in terms of data outputs and coverages, but the instruments differ markedly in their modes of operation and their data rates. Some on-board processing is necessary to reduce the instantaneous transfer from the HIRIS instrument, with concommitant planning and command support for spectral and spatial editing. The HIRIS instrument will only take data in response to user requests, while the MODIS-N and MODIS-T instruments will operate on a full-time duty cycle (different spectral channels for day and night). The MODIS-T pointing operations require planning and control support as well. Both the HIRIS and MODIS allow for updates of schedules and commands for targets of opportunity and instrument emergencies. To accommodate requirements for real-time and near-real-time availability of the science data for field-experiment support and instrument health monitoring, both MODIS and HIRIS will produce low-rate data streams from their science data.

Basic limitations on real-time and near-real-time data transfer exist because of limited Eos access to the Tracking and Data Relay Satellite System (TDRSS), the primary medium of data communications from space to ground. The onboard processing capabilities of the Eos polar platforms relative to MODIS and HIRIS are still to be completely defined. The desirability of a number of onboard processing functions is recognized in the Eos community (ref. 27): buffering complete scans of data to sort measurements by channel before packetization; data compression; generation of products that could be used for instrument control, e.g., setting detector gains for land or sea, or altering sensing routine based on cloud cover; priority packet addressing to support real-time monitoring and near-real-time support of field experiments; building data packets from several instruments for ancillary and engineering/housekeeping use or for the ground data system use; and command and scenario storage and execution functions; e.g., sunglint avoidance, automatic gain changes for high solar zenith angles, and internal calibration sequences.

A very conspicuous need for onboard data sensing/processing is cloud-cover assessment as a preface to some instrument data takes, particularly in view of the continuous global coverage of some instruments, and the certainty of obtaining and transmitting large quantities of useless data to be filtered out at one of the ground-processing data output levels. This need is emphasized by the fact that on any single day, about half of the Earth's surface is obscured by clouds (ref. 28). Conversely, some instruments look for clouds, only, and could similarly benefit from cloud-cover (pattern) "knowledge" through a look-ahead sensor or knowledge base formed from sensing on immediately preceding orbits.

It appears that possibilities exist for significant enhancement of quick-look capabilities of the Eos via an onboard general processing system such as proposed in the ISES. Significant needs are presently being met in near-real-time and quick-look applications through Landsat and NOAA operational satellites, as discussed earlier. However, the fact that extensive ground processing is necessary to create a usable database from the quick-look data indicates opportunity for eventually improving the timeliness and efficiency of use of the data through onboard pre-processing activities and more extensive direct-to-user capabilities.

Table 1 lists a variety of experiments under consideration for Eos payloads that have potential applications to vegetation and land-use and represent opportunities

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both individually and in groups for enhanced data return through the ISES. Tables 2 and 3 present some examples of applications (needs) for which near-real-time data access might be enabled through the ISES.

Support of In Situ Experiments and Research

The Eos concept puts heavy emphasis on field measurements and ground-based analytical work, to complement the extensive satellite instrument measurements. In some cases, field measurements or ground-based database constructions may be the primary database, with the satellite measurements providing supplementary information; and in other cases, the converse relationship applies. In either case, close and timely coordination of the Earth-based and satellite-based data sets is very important to the full accomplishment of Eos objectives. The EosDIS and associated systems provide means to address some of these needs, particularly with respect to HIRIS and MODIS. However, since it may be up to 24 hours before Level-0 data is available for Level-1 processing, some timeliness may be missing in the coordination of field experiment work and satellite data. A dedicated onboard processor and communications package has potential for improving information exchange and synergism between field measurements and satellite measurements, particularly when communications among several experiments may be necessary.

Experiment Base for Evolving Technology

A computational and communications package on Eos would provide real-time in-space inputs to support prototype developments; i.e., an onboard experiment base for testing and evaluating emerging remote sensing technologies. As stated by Katzberg, et al. (ref. 2), "New technology is rarely used because it is not mature; and by the time it gets mature, it is no longer new." Use of relatively new technology in spacecraft operational systems seems unlikely to happen until an onboard experimental base is first established in an opportune (e.g., Eos) environment to test new technology in parallel with and in conjunction with operational systems. Flight simulations and extensive ground testing before introduction into flight application has an important role in early development of new systems, but there appears to be a beneficial role, too, for onboard testing and evaluation, to accelerate introduction of newer technology into dedicated flight systems and to provide information and insights that cannot be gained from ground tests and simulations alone.

Concluding Remarks

It is clear from a review of the current state-of-the-art of remote sensing that the term remote sensing connotes a much broader scientific field than the name literally covers. Smart sensors have served to broaden the concept, but to think smartly about remote sensing now, one has to think about sophisticated image processing; human vision modeling; computer (machine) vision; artificial intelligence; expert and knowledge-based systems; databases; GIS's; learning (neural) systems; advanced communications; and the most modern technology in sensors, cameras, scanners, radiometers, interferometers, and spectrometers. It seems accurate to say that a technological revolution is occurring in remote sensing. Pre-occupation with the data volume and complexities of image/data processing may largely account for the relatively modest current efforts toward application of onboard processing technology.

This paper was written to report the results of re-examining the needs for onboard processing and communications and direct-to-user data communications in remote sensing, relative particularly to applications involving the sensing of vegetation/forest cover and land-use assessment and planning. The evaluation is general to the field, but is focused on the Eos program and a proposed experiment for Eos, the ISES. To assess needs for onboard computer/communication resources for Eos, it was necessary to look at the state-of-the-art activity in these applications of remote sensing and to consider the problems being addressed and the trends in relevant ground-based research.

Particularly prominent in current remote sensing research is the emphasis on further advancements in GIS's, incorporating versatile database management systems for manipulating both spatial information, and the thematic attributes of that information. Through these systems, improvements are possible over traditional methods of capturing, storing, updating, analyzing, and displaying mapped natural resource data. It is well recognized now that the construction and maintenance of a GIS is an essential tool in any information or intelligence analyzing program dependent upon the acquisition, storage, and quick retrieval of large amounts of data relative to any portion of the Earth's surface. GIS technology allows the scientist to process and interrelate many more kinds of data than was previously feasible and opens opportunities for possibly providing new scientific understandings of a variety of topics (problems); e.g., assessment of a country's energy and mineral potential and assessment of hazards due to natural and man-made occurrences (ref. 10, p. 270).

The need is well recognized for eventual application of artificial and neural-type intelligence and expert system technology to database manipulation, and a significant amount of research is being so directed. Until more progress is made in such systems, much reliance will continue to be made upon human intelligent interaction to cope with the complexity of the data management processes. It has been recently proposed by some researchers that in lieu of the goal of completely autonomous systems, semi-automated systems in which humans interact with expert systems, may be the practical approach (refs. 29-31). Consistent with this thinking, it seems that a next logical development, concurrent with reasonable progress in such ground-based semi-automated systems, would be the introduction of semi-automated expert systems and smart sensors for onboard instrument control, data editing, and pre-processing. Such developments would also reinforce the long-term methodology of development of the Eos Data Information System, as presented in reference 32. The need is expressed there for incorporating within the EosDIS an "iterative learning process that is directed toward evolutionary modular or 'test bed' information system concept development." Such strategy "provides a reasonable environment to implement and evaluate concepts and advanced technologies with minimal risk of impairing system performance, integrity, maintainability, and security." The proposed ISES appears to be timed and tailored to serve as the onboard complement to such a ground-based EosDIS test-bed. At the same time, the ISES concept incorporates enhanced quick-look capabilities for Eos instrumentation, addresses direct-to-user data and communications needs, and includes support for coordinating field experiments with satellite experiments.

Appendix

Remote Sensing Instrumentation

Photogrammetric Cameras

Photographic systems have evolved from ground-based ones to aerial systems and then to a long sequence of spacecraft-based systems. Photographic data products played a very significant role in stimulating further interest and advancements in remote sensing, and they have continued into the 1980's era in Space Shuttle and Spacelab experiments. Photogrammetric systems have several advantages (ref. 1): very high geometric resolution for large formats; relatively simple instrumentation and geometric data evaluation; very high geometric accuracy; and possibilities for topographic information generation through stereographic imaging. At the same time, such systems have many limitations, compared with some of the more recently developed remote sensing systems. For example, photographic systems provide only information on the visible and near infrared reflecting properties of the Earth's surface, since they are limited to the spectral region from 0.3 to 0.9 micrometer. In addition, they are characterized by limited spectral resolution, non-linear radiometric effects, and use of film recording media with limited physical recovery capability.

Television Cameras

The Return Beam Vidicon (RBV) cameras used on Landsats 1-3 are well known uses of TV cameras on satellites. This type of sensor was used earlier on some weather satellites. RBV's were troublesome because of power problems that resulted in early failure. They provided high topographic detail, but radiometric resolution limitations reduced the usefulness of the data. Video systems can provide users with near-real-time imagery that is useful in applications requiring rapid turn-around-time, while not requiring high resolution. In addition, the electronic format of video data is compatible with computer image processing techniques, and it provides improved spectral resolution and extended spectral range, as compared with photographic systems. Recently, color IR video systems, designed around video tubes, have been used in remote sensing applications, at least in aerial and ground vehicles (ref. 33). Solid-state cameras (CCD's) have also been used in space remote sensing applications (e.g., ref. 34).

Ultraviolet, Visible, and Infrared Multispectral Radiometers and Imaging Spectrometers

The scanning radiometer is now the most commonly used type of instrument for satellite remote sensing in the visible and infrared spectral regions, covering the spectral range 0.3 to about 14 micrometers. The radiation sensed is either reflected solar radiation or radiation emitted from the Earth's surface, spectrally selected by filters, prisms, or grating systems. The basic design of the instrument involves a mirror system to focus radiation from the Earth's surface onto a detector and a mirror scanning mechanism to scan the instantaneous field of view along a line perpendicular to the satellite's orbit. The satellite image is constructed from a series of adjacent scan lines which result from the orbital motion of the satellite.

There is a trend toward replacing scanning systems in radiometers by solid-state multilinear arrays (MLA) detectors. Scanners inherently are susceptible to mechanical wear and failure. The MLA is a linear array of sensors, each of which creates a pixel of data along a line perpendicular to the direction of the satellite motion in its orbit. Present systems, also referred to as pushbroom scanner systems, are limited to wavelengths out to the near infrared.

Lidar, or laser radar, is an active (provides its own target irradiation) sensing system similar to microwave radar, operating in the UV to near IR regions. Such a system uses a laser to emit radiation in pulsed or continuous mode through a collimating system (ref. 35). The radiation that is returned is collected by a second optical system that focuses it onto a detector. Both the backscattered signal intensity and delay can be measured. The delay provides range measurement, while the backscattered intensity provides information about the size and the physical and chemical composition of the target.

Microwave Radiometers

Microwave radiometry is based on the spectral region from one to 300 micrometers (refs. 35 and 36) and is categorized as active, passive, imaging, or non-imaging (profiling). Radar is the most well known subdivision of active microwave radiometry. Pulses of microwave power are transmitted from an instrument toward a target and measurements are made of the reflections or scatterings returned to the same instrument from the different regions of the target. A radar scatterometer is a non-imaging active system for measuring the radar backscatter of terrain as a function of incidence angle (ref. 5).

Geometrical and electrical characteristics are the principal factors that influence the magnitude of the radar return signal for active systems. Geometrical effects include the relative orientation of the object and sensor, as well as the surface roughness and its magnitude relative to the wavelength (wavelength is also important in determining atmospheric penetration). At any chosen wavelength, radar signals may be transmitted and returned in various combinations of polarization, as empirically determined to be most useful. Smooth (relative to wavelength) surfaces in general reflect the signal away from the sensor, whereas rough surfaces return more of the signal, but a smooth target may be so oriented to cause a strong return. Objects or combinations of object surfaces may create the special case of an effective corner cube reflector, which results in multiple reflections and high signal return.

The basic configuration for aircraft active microwave radiometry is side-looking radar (SLR) or side-looking airborne radar (SLAR), so called because the antenna is fixed below the aircraft and pointed to one (or both) side(s), producing continuous strips of imagery parallel to the flight line. Conventional (real aperture) SLAR systems are relatively simple in design and in data processing requirements, but are rather limited in resolution and are constrained to relatively short-range, low-altitude, and short-wavelength operations. Associated with these limitations are limited aerial coverage and increased atmospheric attenuation and dispersion. These limitations are overcome in synthetic aperture radar (SAR), or coherent radar systems, more suitable in resolution capability for satellite applications. While these systems use a short physical antenna, they synthesize the effect of a very long antenna via the aircraft motion and special doppler data processing. SAR is more practical than SLAR for spacecraft operations, as well as for most aircraft applications. The disadvantage trade-off is much more complicated data processing.

With passive microwave sensing, the target's naturally occurring radiation is sensed. The emittance of the target varies with observation angle, polarization state, wavelength (frequency), and surface roughness (relative to wavelength). Brightness temperature is a commonly measured physical parameter; i.e., the temperature of a blackbody with the same emissive power as that of the target sensed by the microwave radiometer or scanner. The temperature and temperature distribution in the target body (surface feature), as well as its electrical and thermal properties, affect the quantity and spectral nature of the radiation received by the microwave measuring system. For a given target, the passive microwave signal may involve these components: 1) emitted radiation due to the material characteristics and temperature; 2) atmospheric radiation; 3) surface reflection originating with the sun or sky; and 4) radiation transmission from the subsurface region of the target. Therefore, for passive microwave signals, the signal strength and character over a given object depend on the object's temperature, emittance, reflectance, transmittance and the incident radiation. These dependencies, in turn, are affected by the object's electrical, chemical, textural, and shape characteristics, and by the angle from which they are viewed. Only very low radiation levels are available from passive microwave sources; therefore, a relatively large antenna beam width is required to collect sufficient power to provide a detectable signal.

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Table 1. NASA Eos Instruments Supporting Vegetation and Land-Use Research Applications

Clouds and the Earth's Radiant Energy System	CERES
Thermal Infrared Ground Emission Radiometer	TIGER
Stratospheric Aerosol and Gas Experiment III	SAGE III
GPS Geoscience Instrument	GGI
Earth Observing Scanning Polarimeter	EOSP
Moderate Resolution Imaging Spectrometer	MODIS
High Resolution Imaging Spectrometer	HIRIS
Synthetic Aperture Radar	SAR
Geoscience Laser Ranging System	GLRS

Table 2. Quick-Look Applications in Forestry

Drought indices measurement

Fire-danger monitoring

Fire-progress/control monitoring

Infestation/mortality detection and monitoring

Acid rain/pollution assessments

Volcanic effects on timber measurement

Forest inventories maintenance/updating

Air pollution impact on forest ecosystems measurement

Table 3. Quick-Look Applications for Vegetation

Drought indices and adequacy of irrigation sources measurements
Rangelands fire-danger monitoring
Wheat belt growth progress and crop yield estimations
Infested areas isolation for treatment
Pollution damage assessment
Growth cycle in major crop belts--monitoring
Vegetation stress assessment
Biomass measurements in deserts/dust-storm assessment
Storm-damage/soil-erosion/flood-inundation assessment
Herbicide drift-damage determinations
World-crop information gathering
Crop production and quality--early forecasts