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**Remote Sensing and GIS Integration:  
Towards a Prioritized Research Agenda**

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# **Remote Sensing and GIS Integration:**

## **Towards a Prioritized Research Agenda**

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### **Abstract**

This paper briefly reviews the activities of the National Center for Geographic Information and Analysis Research Initiative 12: the Integration of Remote Sensing and Geographic Information Systems. In particular, it presents a prioritized research agenda, focusing on areas which are both important to the problems of GIS-RS integration, as well as amenable to significant breakthroughs in the near term.

### **1.0 Introduction**

Earth observing sensor packages on aircraft and spacecraft and advanced image processing technologies provide researchers, resource management and policy making personnel with powerful tools for producing and analyzing spatial, spectral and temporal information. Geographic Information Systems (GISs) provide researchers, resource managers, and decision makers with a tool for effective storage, manipulation and analysis of remotely sensed and other spatial and non-spatial data and information, for scientific, commercial, management, and policy oriented problem solving. As such, these technologies may be used to facilitate measurement, mapping, monitoring, modeling, and management (see figure 1) for a wide range of users.

GISs not only facilitate the use of many types of data, GISs also permit data to be updated readily. Indeed, the synergism between remotely sensed data for updating spatial data/information, and the use of GIS for improving the information extraction potential of remotely sensed data, is a major advantage of the merging of these two powerful technologies. Geographic information systems:

- facilitate access to a variety of data and information,
- facilitate the creation, updating and modification of maps,
- improve our ability to model important science research questions and operational resource management tasks
- enhance graphic display of complex phenomena, and thus, our understanding, and
- provide tools for enhancing decision making.

There is an increasing awareness of the importance of the integration of remote sensing and GIS technologies as shown by the themes of a number of recent workshops and conferences both within the United States and abroad. The trend toward more emphasis on the application of integrated geographic information systems (IGIS, defined here as systems which can process remotely sensed imagery as well as raster and vector data sets in a consistent fashion) stems in part from:

- improvements in the quality and quantity of remotely sensed data available,
- improvements in computer hardware and software,
- increasing population and competition for natural resources,
- decreasing resource availability and environmental quality,
- recognition of the global nature of problems,
- an increase in the number of public and private organizations working on local, national, regional and international problems, and
- the creation of larger and larger data bases to provide information in various scales.

These important trends are definitely indications of broader changes that are developing in society in general. They make it imperative for us as researchers to not only improve remote sensing and GIS technology but to widen our focus in order to examine a greater range of science, management, and public policy related issues which can be impacted by an improved synergism between these two technologies.

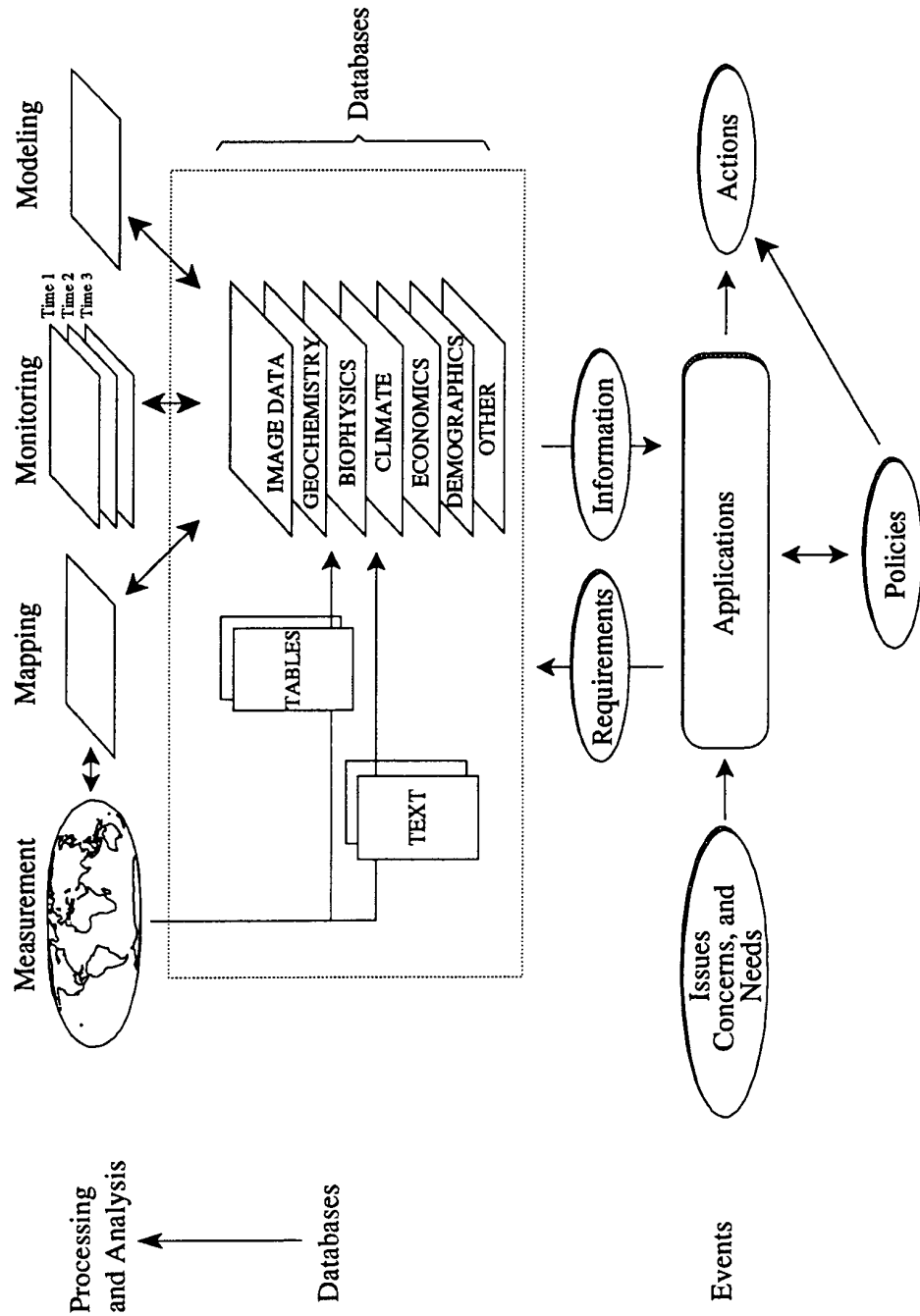


FIGURE 1. GIS DEPICTED AS A DECISION SUPPORT SYSTEM. A GEOREFERENCED DATABASE HAS INPUT TO AND DERIVES INFORMATION FROM MEASUREMENT, MAPPING, MONITORING, MODELING, AND MANAGEMENT ACTIVITIES IN SUPPORT OF POLICY ANALYSIS AND DECISION MAKING.

Both GIS and remote sensing have moved well beyond the novelty stage. These two powerful technologies are being merged. Researchers in many fields have realized that the synergism created by this merger has the potential for a significant increase in information extraction and analysis for both applied and research operations. Nevertheless, if this potential is to be realized - if we are to use these tools to move to higher levels of understanding - there are a great many steps to be taken.

This paper presents key results from a series of meetings and continuing research and educational activities sponsored by the National Center for Geographic Information and Analysis (NCGIA) on Remote Sensing and GIS integration. NCGIA is a consortium of three institutions: the University of California Santa Barbara (UCSB), the State University of New York (SUNY) Buffalo, and the University of Maine, Orono. NCGIA activities focus on three areas: research, education, and outreach. Education and outreach activities involve curriculum development and dissemination, participation in workshops and conferences such as this one, and cooperative activities with public and private organizations. A primary activity of NCGIA, to date, has focused on the conduct of research initiatives. The initiative model brings recognized experts in various fields of spatial analysis together to prioritize research in a given area. The initiative upon which this paper is based is titled Integration of Remote Sensing and Geographic Information Systems. This initiative is often referred to in some NCGIA literature by its NCGIA initiative number, 1-12. A number of activities have been associated with this initiative, including various meetings, a major National Symposia session, a special issue of Photogrammetric Engineering and Remote Sensing (Vol. 57, No.6), a conference proceeding volume (Star, 1991), a specialist meeting publication, several presented papers on collaborative research, a book in preparation, and curriculum development activities. This paper in part draws heavily on material published in the special issue of Photogrammetric Engineering and Remote Sensing, dated June, 1991. We gratefully acknowledge the contributions of the many authors of the articles published in this issue.

This paper, however, moves beyond this material and presents our prioritization of research needs in the area of remote sensing and GIS integration. NCGIA Initiative 12: Integration of Remote Sensing and GIS Technologies, combined the best efforts of individuals from a variety of disciplines to define and prioritize key research topics in remote sensing-GIS integration. This material is discussed first grouped into the five major subheadings which were developed during the various meetings: Data and Data Access, Environmental Analysis, Error Sources, Institutional Issues, and Future Computing Environments.

Research needs as well as priorities are discussed in the following sections. The authors' prioritized research agenda follows. The agenda represents our further analysis and understanding of key issues in this area based upon continuing research related to I- 12.

We acknowledge the continuing support of the National Science Foundation, National Aeronautics and Space Administration, U.S. Geological Survey, U.S. Environmental Protection Agency, the Defense Mapping Agency, Oak Ridge National Laboratories, and EG&G for their support in developing the material presented in the paper. We also thank our co-leader of this initiative, Frank Davis, and Anton Inderbitzen for their reviews of an early draft of this manuscript.

## **2.0 Evolution of a Research Agenda**

Research agendas in both remote sensing and GIS are, at a minimum, difficult to develop, worse to prioritize, always controversial, temporally fragile and subject to the very real biases of their authors. Trying to develop a prioritized agenda on research directed at the integration of remote sensing and GIS is likely somewhere between a square function and an order of magnitude more difficult than the development of a prioritized research agenda for either topic alone. The material which follows should be considered only a step in a process, not an end in and of itself. It is very much our thoughts on this subject at this point in time.

As a step in the overall process one of the authors reviewed the results of 112 activities accomplished through September 1991 (REFERENCE). As part of this analysis a matrix of common themes was developed, the result of a review of each of the five research areas developed at the specialist meeting, based on overlaps in the reports of the five groups. We realize that this is an imperfect process at best. Yet, it does represent one measure of concern on the part of the community as to where there are issues which require attention. This material was presented at a workshop sponsored by the International Institute for Aerospace Surveys and held in Oberpfaffenhofen, Germany, in September 1991 (Estes, 1992). The priorities can be displayed another way (Table 1) where the themes are presented in descending order by number of groups identifying each topic areas. By ordering the research themes in this fashion we can develop a rough cut prioritization as follows:

Table I: Preliminary Prioritization Based on Frequency of Mention By I-12 Expert Meeting Subgroup

| # of Groups Listing Issue | Issue   |
|---------------------------|---|
| 5                         | Standards   |
| 4                         | Lineage Tracking<br>Raster/Vector<br>Visualization                                  |
| 3                         | Accuracy/Error<br>Education and Training<br>Scale<br>Test Datasets                  |
| 2                         | IGIS Taxonomy<br>Multistage Sampling<br>Spatial Data Catalogs<br>Spatial Statistics |

Arguably, ordering the research themes in this way assists in developing more generic areas for focus and priority. For example, participants in all five subgroups believed that more emphasis on the development of data, hardware and software standards as well as spatial data analysis was required.

In the second tier of prioritization, we find those categories listed by four subgroups. In the case of each of these themes the subgroup that dropped out was the Institutional Issues subgroup; it was this subgroup that did not mention the topic. Lineage Tracking, Raster to Vector Conversion and Visualization were considered priority items by each of the remaining subgroups. The authors do not consider this unusual given the subgroup themes since each of these categories is clearly important to each of the subgroups by which they were identified.

As we move to the next category the reasons for listing became more complex. Accuracy and Error was not listed by the future computing environments subgroup. This is not unusual given that the focus of this subgroup was primarily on systems development related issues. Education/Training was not listed by either the data structures and access or the processing and flows subgroups. These groups were more concerned with techniques, methods and science development; whereas the other three groups which did list Education and Training were possibly more concerned about improving our overall understanding of process. Yet, it is still somewhat difficult to understand why Education and Training was not mentioned, in particular, by Data Processing Flows Subgroup. Scale on the other hand is more straight forward. The reader can readily appreciate why the Institutional Issues and Future Computing Environments subgroups would not list this as an issue of central concern; whereas the Data Structures and Access, Data Processing Flows and Error Sources and Analysis would be very concerned about issues of scale. Finally, the same rationale can be applied to the listing of test data sets by the same three subgroups that listed scale.

When we examine the topics listed by two subgroups the rationale for listing are also fairly straightforward. IGIS Taxonomy, Multistage Sampling and Spatial statistics were each considered significant by both the processing flows subgroup and the Error Sources and Analysis Subgroup. The relevance of each of these research themes to these subgroups should be readily apparent to the reader. Spatial Data Catalogs are significant as a means to improving our ability to locate and acquire data. Spatial Data Catalogs was listed by the Institutional Issues subgroup and the Data Structures and Access subgroup. The reasons here again are intuitively obvious given these subgroups focus.

It could be argued that the listing presented as Table I was, to some extent, preordained by the I- 12 executive committee. The conditions which made this possible basically occurred when the five subgroups were chosen at the second executive committee meeting. Yet, these subgroups were then put forward and validated by I- 12 participants. It was the specialists specifically chosen for their expertise in remote sensing/GIS integration in each subgroup that are responsible for this ranking. As such we must seriously consider that work is required in each of these areas and that the prioritization of topic areas where research is required, seen in Table I, is valid. One might also argue that the overlaps in priorities between the subgroups reflect a certain amount of cross-fertilization during the meetings; there were participants at the meetings (including the authors) who moved between the five subgroups as well as discussions throughout the meetings that crossed these boundaries. Thus, groups may have assumed that some areas of focus were already well-represented by others.

It is difficult, however, to justify this prioritization if we examine needs in specific applications areas where (for example) remotely sensed data would be used to create or update key data layers in a GIS which is being employed as a decision support system. In areas like global change or biodiversity research, just as with location analysis or facility siting, the ability to improve the accuracy of information derived from remotely sensed data is important. This would lead us to place higher priorities on topics such as errors and accuracy, multistage sampling and spatial statistics. What we are saying is that any prioritized agenda is driven by a class of users or a constituency. In the case of the prioritization seen in Table 1, no end use was specified except those broad communities which were agreed upon by each of the individual subgroups. In addition it is critical to realize that specialist meeting participants were not asked whether research was or was not being conducted in an area, nor if the research being addressed was adequately staffed or funded. Instead, the subgroups were concerned with areas where key impediments remain.

Levels of effort and funding are very real considerations in the development of the prioritized 1- 12 research agenda. Is an area of research already being covered? By whom is it being worked, in support of what constituencies or applications? Are the efforts adequate? Are more resources required? In a pragmatic sense all these questions should be examined. To some extent the mere listing of a topic may seem to imply that the specialists considered the activity in the area inadequate. Is this really true? Perhaps; perhaps not. The need to address the question of the adequacy of activity is particularly important when we remember that remote sensing is a technology heavily influenced by developments in the Federal establishment while GIS technology has been largely driven by private industry responding to market pressures (Shelton and Estes, 1979). Suffice to say that the authors believe that it is important to consider these factors when deciding what research is required and which areas should receive priority.

We believe there is more than one path that can be taken to establish priority areas requiring research and many arguments can be made concerning the adequacy of research and resources currently being directed toward any given area. This prioritization can be seen as being primarily focused around the need for funding. Where we believe more resources (both personnel and financial) are needed. The prioritized research agenda which follows is our considered opinion, our best judgment at the present time, of where emphasis needs to be placed to move the combined application of remote sensing and GIS technology forward. Please remember that the concepts presented here are part of a process and that we learn each time this material is presented to a new audience.

### **3.0 A prioritized agenda for GIS Remote Sensing Integration**

Our highest priorities are those topic areas believed to have both the broadest impact as well as the highest potential for early significant breakthroughs (Table 1). Basically, these are research areas where, we believe, insufficient resources are being expended at this time to adequately address the nature of the fundamental issues.

In our second tier we include some areas that are important but will take longer for researchers to make significant progress. Included here too are several areas where research is already underway but more investment of both personnel and funding are required to adequately address the issues involved. We want to be clear that in both these first two tiers significant additional funding above current baselines are required. We hope that federal funding agencies or private industry will take notice and begin to provide the level of resources necessary to effectively conduct the research needed in each of these areas.

In the third tier we list topics which are important but are currently being addressed with sufficient resources at this time, based on our analysis. This is not to imply that the work required in these areas is any less important. Nor does this imply that levels of resources currently being directed at these areas could be either reduced or redirected to topic areas in tiers I or 2. Rather, we do not recommend significant increases in funding for these specific areas at this time. The reader should have the impression that we do not consider this a zero sum effort by any stretch of the imagination; it is not. There are serious research areas/topics which must be addressed. This work will require funding for personnel, hardware and software development. It will require management attention. What is critical here, however, is the full potential of these important technologies will not be reached unless we are successful in expanding current activity in this area.

Viewed another way, we have chosen as our highest priority for recommending expanded research those areas which we believe will advance the scientific, technical and applications potential of Integrated Geographic Information Systems in the most effective and efficient fashion. For category I topics we believe that given increased attention, including funding opportunities from Federal or other agencies or organization and/on directed research from private industry, significant progress in these areas is possible in a two to four year time frame.

In our second category we have placed topic areas which though important we believe that:

- 1) a more thorough understanding of the issues involved are required; e.g., accuracy and error, scale, and time. These are inherently difficult generic issues which will test our ability to demonstrate acceptable results;

2) that current work although promising in some areas will be more difficult and time consuming to implement than some would think at this time; e.g., lineage on heritage tracing, and heterogeneous systems environments; and/or

3) longer range issues which do not lead themselves to 'solution' but must be continuously watched as the science and technologies evolves; e.g., education and training, and spatial information management.

We feel significant advances in these areas are of a nature that a 5 year to 15 year time frame is more appropriate.

In our third category we have a number of topic areas under the heading of infrastructure building. This work impacts all segments of the community from system developers to research and applications users. These are topics which, we believe, are important but are being addressed within the community at what we consider to be an acceptable pace at this time, although many of us wish the standards efforts would move at a faster pace. It is important to note that just because a topic is listed in this category does not mean that it is any less deserving of support than topics included in categories I or 2. It does not; and, while this may at first seem somewhat confusing within the context of this prioritization, it is really quite straight forward. Topics in this category are being worked by NASA, USGS, EPA, and a variety of institutional, industrial and academic participants. This work must continue. This work must be funded. But, more significantly, this work must be better coordinated at a variety of levels and progress and result made more widely known in both the remote sensing and GIS communities. Methods for and efforts to effect this improved coordination and dissemination must be pursued with vigor. We must do a better job of involving more of the community in these efforts where appropriate.

The research areas listed in Table 11 are in priority order. We believe the area deserving of highest priority at this time is the area of data format and structure conversion. We need to be able to move more efficiently to convert data from one format into another and to move between raster and vector data more effectively. While some may argue that this area represents a Odone deal' the authors do not. In particular, while there is certainly software with these functions, there is not, in our view, an understanding of the effects of these functions on the quality of the resulting derived data layers. While systems are plentiful with a 'format conversion button', there is insufficient understanding of how these functions affect the decisions we reach with these software tools. We do, however, feel that significant advances can be made here in the near term and encourage funding agencies and individuals or groups with innovative approaches to problems in this area to redouble their efforts here.

Advanced feature extraction techniques and methodologies are ranked second in our priority. We do not feel that is area has been given the attention it deserves for more than a decade. There are pockets of activity in the community and some excellent work is being done. Yet we know of no major funding agency with a focused program of funded research in this area. The background for this lack of research goes far beyond the scope of this paper. Such a discussion would make an interesting thesis or, dissertation topic in and of itself. We as a community, largely due to lack of opportunities for funding, have not pursued research in this area with sufficient vigor. At a time when major global change research efforts on tropical deforestation are employing manual image analysis techniques from single band satellite imagery and we are using unsupervised clustering and band rationing of Advance Very High Resolution Radiometer (AVHRR) data for regional scale change detection, we have definitely missed something along the way. We must stop and rethink our activities in this area now, reconsider our technology basis. We must begin to explore the full potential of integrated GIS/remote sensing analysis for feature/information extraction from remotely sensed data

Table II: -12 Co-leaders Prioritized Research Agenda

## 1. Science and Technology Research and Development

- A. Data Format and Structure Conversion
- B. Advanced Feature Extraction
- C. Spatial Analysis and Modeling
- D. Visualization

## 2. Improved Understanding

- A. Education and Training
- B. Error and Accuracy
- C. Scale
- D. Time
- E. Spatial Information Management
- F. Heterogeneous Data and Data Structure
- G. Lineage or Heritage

## 3. Infrastructure Building

- A. Standards
- B. Spatial Data Catalogues
- C. Test Datasets

Our third area is the broad topic of spatial analysis and modeling. This is a critical area of research need. It could be argued that this area should deserve the highest priority. We have chosen not to give this area that rank largely because we feel that advances in areas one and two are required before we can fully realize major advances in this area. This does not mean that significant advances in the integration of spatial analytical techniques and modeling cannot be accomplished now. The evolution of object-oriented database technologies is leading to new integrated data models for managing vector and raster data (e.g., Stonebreaker, 1990). Research activities should be pursued and funding opportunities must be expanded dramatically if we hope to apply these and other technologies to satisfy the information needs of the wide range of potential users of these data - the global change research scientists; to the city or county planner, to the farmer in the field, the lawmaker in Washington, D.C. or Niamey, Niger for that matter.

The fourth and final topic in our first grouping is visualization. While there is currently a great deal of activity going on in this area more still needs to be done. Users need to be able to more effectively view their analyses as they progress. We must be able to convey attributes of data - such as data quality and lineage - more effectively. We should consider optimal methods for the presentation of data to decision makers of all levels. We must move from 2D and 2 1/2D graphic visualization to more realistic apparent 3D and 4D graphic visualization. Such developments we believe would add significantly to our understanding of the wide variety of complex interconnected processes occurring around us.

For the purposes of this discussion we have chosen the preceding topic areas as being focused on science and technology. Again we feel that research and development can have higher near-term payoffs for the broad user community than are likely to occur in those areas that follow. We will use the term improved understanding to describe what we believe are the next tier of priority research and development activities. These are areas which we believe will require more sustained focused research and development (5-15 years) for significant progress. Indeed it is even difficult to say that optimal solutions will be achieved here as what might be optimal for one class of user may not be for another user.

It is not surprising that researchers from an academic institution would put education and training high on our list here. It might be argued that education and training is more an infrastructure issue and should be included in our text tier of priorities. In one respect we agree. Education and training is key to a solid infrastructure. Yet, one of the criteria for inclusion in the next tier of topics is that activities in these areas are being adequately addressed and funded at present. In the area of training and education this is certainly not the case. While there are a number of efforts currently underway to improve education and training in remote sensing or GIS, the authors are aware of only one which is focusing on the integration of remote sensing and GIS. This effort, which is still very much in

the formative stages, does not in our opinion currently have sufficient funding or overall participation to carry the project to successful completion. Project personnel are in the press of seeking the resources required and this project and others in remote sensing and GIS at levels from kindergarten through graduate deserve funding agency support. There is an old saying: if your horizon is one year, plant rice. If your horizon is ten years, plant trees. If your horizon is one hundred years, educate your children. We must do a better job of educating people to the true potential of these combined technologies.

The issue of Error and Accuracy is certainly an area where a great deal of effort is needed. There is no doubt that this is a very important area and deserves considerable attention. Our reasons for listing this area here is that we are not entirely sure significant progress can be made in this area in a one to three year time frame. Indeed, the same comment with respect to timing can be made for issues of scale and time as well.

Each of these three areas - error/accuracy, scale and time - are fundamental attributes of spatial data; while it can be argued that several other topics are also attributes of spatial data we would argue that these three are fundamental. Long range thorough research is certainly needed in each of these areas. A problem here is that research of the type needed is not currently high priority for major funding agencies. Some agencies feel that their missions include these topics; however, there are other issues of priority importance where there are shorter term payoffs. Other agency budgets are so small and there are so many demands on these scarce resources that serious efforts to mount a major research effort here is not possible.

What is happening today is that we are largely picking around the edges of these areas. Researchers working on other topics are learning how problems in dealing with error accuracy, scale and time impact their particular basic science or applications problem. Yet, since these issues are not the focus of their work they do not receive the directed attention they deserve. Perhaps this is as it should be. Perhaps the problems here are so complex and the benefits to improved understanding insufficient to support major research efforts in these areas? After all we have been, are, and will continue to make decisions based upon data whose error and accuracy attributes are not fully understood. We cannot deny that data/information generated at one scale are extrapolated to other scales at times without sufficient concern for the impacts that sample design, spatial autocorrelation, or multiple collinearities might have on the results at the new scale.

We all know or should know of instances where data acquired at one point in time have been used to verify data collected at another point in time. These are only examples from a long list of ways in which we as researchers and applications users have both used and abused error/accuracy, scale and time. There are good and valid reasons for doing so but we should make it more clear to all that we understand what we are doing and why. It is not only because the implications and impacts of these topics are not always fully known, but it is equally true that addressing these issues within a given project may be prohibitive in time and cost. As was recently pointed out in several meetings on similarly but unrelated topics attended by the lead author: it would cost more to verify the accuracy to the mop than to produce it in the first place.

We must recognize these topics and others in the spatial data analysis area as issues of very serious concern and encourage major long-term, well thought out, proposals from individuals, groups or institutions to address these issues. Indeed, if we can have Long Term Ecological Research Sites, or a long term well funded center such as the National Center for Atmospheric Research, or the multiplicity of federally funded laboratories for research (e.g., Los Alamos, Oak Ridge, Fermi), why shouldn't we have similar **well funded** center or agency-based efforts on these topics, where an improved understanding can lead to better decision making concerning our ability to manage our planetary resources to the benefit of all peoples of the earth?

The final issues in tier two are spatial information management, heterogeneous computing environments and lineage (or heritage) tracing. Here are areas where research is required that, it could be argued, should properly be the focus of industry. These are certainly topics deserving of attention and important to a wide user community. However, we believe that significant improvements in the state of the art in these areas is beyond the bounds of either the academic community or governmental agencies. This clearly reflects our research biases: the private sector is probably more aware of the requirements for these kinds of operational capabilities, and potentially more able to move rapidly with prototyping and joint development with large user agencies. That does not mean that academics or government researchers cannot or should not participate in work here; nor that the legitimate need of government agencies for improved capabilities in these areas cannot be used as a justification for the conduct of research on these topics. What we are saying is that industry needs to work the issues involved here.

Our final tier of topics are those which we feel are currently being worked with sufficient resources. We group these infrastructure issues together in this regard. Included here are three topics: standards, spatial data catalogues, and test data sets. With the arguable exception of the development and dissemination of test data sets these are provided with adequate resources at this time, and the initiation of major new efforts could be counterproductive. For example, there is no need to duplicate the standards activities that are being carried forward under the auspices of the Federal Geographic Data Committee or the Interagency Working Group on Data and Computation. These groups already interface with a wide segment of the community and have established review and oversight mechanisms. An observation which must be made, however, is that there are many who wish that the efforts of these

organizations would move faster. Let us hope that it does not take ten years to implement the vector profile of the Federal Spatial Data Transfer Standard in common spatial data processing systems. In this area it may be better to implement and evolve a less than perfect standard rather than to continue to seek the holy grail of perfection and delay implementation. Standards purists may blanch at this but operational users need standards **now!**

Spatial data catalogs are being developed by a wide variety of organizations today, to provide improved access to data, spatially referenced or otherwise. The National Aeronautics and Space Administration, the United States Geological Survey, the United States Environmental Protection Agency, the United Nations Environment Program, the International Geosphere Biosphere Program, the Nature Conservancy, and the United States Research Libraries Group are but a few examples of organizations who focus on this problem. At the core of these efforts is what is termed metadata, which is defined as data about data. Issues of access to metadata and formats and structures overlap those in the standards area. Overarching this area, however, are questions of networking and on-line access to these types of data. Advances here will require more coordination among major data depository/providers and stronger efforts directed at both catalog and inventory interoperability.

The final area of priority is the development and wider spread use of test data sets. These data sets are required to fully evaluate procedures developed in a number of other topic areas such as advanced feature extraction or processing flows. There are today a limited number of well documented, verified data sets in differing environments. These need to be better utilized to test ideas, concepts, methodologies involving feature extraction, processing flows, issues of accuracy and error and so on. From the EPA Chesapeake Bay data set, to the NASA Ames Research Center Oregon Transect, to the First International Satellite Land Surface Climatology Project Field Experiment test site in the Konza Prairie of Kansas, the multivariate data provided with the GRASS distribution, and U.C. Santa Barbara's Goleta and Vandenberg USGS 7.5 minute Quadrangle data sets, a number of well documented sets of data of varying coverage, scale and themes exist. What is needed is some central focus, or clearinghouse if you will, for alerting the community about their existence as well as means to access them. This is a much needed function and should be taken on by some institution. The authors would recommend the USGS EROS Data Center (EDC) as a logical place for such an activity. EDC as the National Satellite Land Remote Sensing Data Archive is the logical place for information concerning these test sites.

#### **4.0 Conclusions**

The material presented here, we believe, deserves careful attention. The governments of the world are spending billions of dollars preparing remote sensor systems to monitor our environment. Industry is making large investments, developing GIS systems and database creation tools for various applications. We argue that remote sensing and GIS technologies are intrinsically linked. To be effective, key GIS data layers must be as accurate and up-to-date as practical. Remote sensing can help update GIS data layers. Remote sensing data often require correlative data to improve the accuracy of geospatial analyses. GIS data layers can be employed to help supply such information. It is important then that we get on with research of the type discussed here, to begin to remove serious impediments to the integration of remotely sensed and GIS data.

We do not believe that there is a need to redirect funds from some other area of either remote sensing or GIS research. What is required is the realization of the need for accurate information on the current status and trends in our environment. This information is urgently needed at scales from local to global. Remote sensing offers us the only practical means for the collection of many types of basic environmental data at any scale above local. Yet, to be effective we must integrate these remotely sensed data with other data, extract information, and convey that information to policy makers environmental planners and resource managers in an effective fashion.

We are not doing this at this time. Yet, there are signs that governmental funding agencies (and the legislators they depend upon for their funding) are coming to a new understanding of the potential of these technologies. Hopefully this realization will equate to new resources being directed towards these research areas. We must not consider funding for research in this area is a zero sum game. We cannot and should not accept that existing funds in remote sensing research areas, in particular, should be redistributed on the basis of this agenda. Rather, we hope this agenda can be used to influence funding agencies and industry to realize the significant benefits that can accrue from directing new resources towards priority areas.

In an era when we are trying to understand the Earth as a closed life support system, we cannot fail to address these needs. At a time when global climate change, loss of biological diversity, and sustainable economic development are in the forefront of public policy, we must address the needs of the policy making establishment for these technologies. By what other means can we effectively acquire up-to-date data, integrate it, analyze it, and provide decision support information on the status of our national and global environment for policy makers other than through the integrated use of remote sensing and GIS?

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The following represent a record of the comments made by both the panelists and by the audience after Prof. Estes's paper.

Prof. Manfred Ehlers, University of Osnabruch, Vechta, Germany; Prof. Ehlers was an early participant in the NCGIA initiative. In his response, Prof. Ehlers made the following specific points:

- We cannot cope with data volumes from remote sensing multitemporal-multispectral datasets volumes, without GIS as a means to support our creation and update of data about the earth,
- We must avoid creating more graveyards of information, by developing improved ways to extract the information we need from these remote sensing systems of the near future.
- There is a strong need for GIS information (as well as an understanding of natural variability of this information such as seasonal change) to better understand the remote sensing datasets.
- I was put on this panel in part to provide a European perspective: one might ask is there a European perspective?  
In Europe language is more of a barrier to coordination and exchange than in the U.S. - Prof. Ehlers feels he knows more on the U.S. programs than on French or Spanish efforts in Europe.
- Development of model-based image analysis and understanding based on remote sensing/GIS integration is a major opportunity for the field, and an area which should be accorded priority
- Priorities should include: structures, semantics, uncertainty issues, implementation - but more directed towards the integration of RS-GIS; NOT on either separately!
- Prof. Ehlers feels we need to focus on what he terms Geoinformatics: a combination of RS-IP, GIS, GPS, digital photogrammetry, computer sciences, and cartography.

Dr. James Lawless, NASA Headquarters, Office of Mission to Planet Earth. Dr. Lawless made the following observations in his presentation:

- Why is there a lack of funding and support for the integration of remote sensing and geographic information systems among the U.S. federal agencies? What venues are appropriate to provide support for these topics?
- Perhaps it is up to the science and technology communities to explain to agencies like NASA why these are important subjects to support: GIS process and approach are not remote sensing per se, but information extraction. If these are important it is up to the community to make the case. How do they support the science and applications of remotely sensed data? How do they help other agencies perform their missions?
- NASA, in particular, expects a process-level understanding of the phenomena under study; the ozone hole study is a successful example of observations leading to science understanding, which has then led to public policy. How might improved integration of remote sensing and GIS facilitate this process in the future?
- To date, GIS and remote sensing-GIS integration needs have not been couched in terms of science requirements - for example, how does a policy-making decision need the science, technology, and infrastructure developments suggested? Technology development does not carry the day at NASA at this time.
- There is also a potential industry connection to the discussion: perhaps there is an impression within the funding agencies that the field is already mature, and thus, not in need of the research and other investments mentioned in Prof. Estes's paper. If this is not the case, then the community must make it clear that this is not the case.

Dr. John MacDonald - Chairman, MacDonald Dettwiler, Richmond, B.C. Canada

I will be speaking today from the viewpoint of the operational use of Remote Sensing and GIS. These two terms are sometimes confused or ill-defined. It is useful, I think, to look upon remote sensing as measurement and upon GIS as abstraction. This may serve to eliminate some of the confusion in our discussions.

Let us first deal with the problem of measurement. If the measurements scientists make today are going to be useful to their successors in understanding the evolution of the Earth system and humankind's effect on it, accurate calibration of these measurements is critical to the creation of data sets which describe the state of a region of the Earth system at a particular point in time. Measurement places a strong emphasis on error and accuracy. Traditionally, remote sensing has not emphasized the quantitative approach, however

today there is movement in the community towards more quantitative treatment of observations. For the reasons stated above, the global change program requires this quantitative approach, and requires an emphasis on knowing the error bounds on the measurements. One cannot build physical models of Earth processes without being quantitative, without a knowledge of accuracy.

To understand the state of the land, one must measure it through the atmosphere, and to understand the state of the atmosphere one must view it against a background of the surface reflectance. Thus, from a remote sensing viewpoint separation of the land and atmosphere is a difficult process. The shape of the land is a vital component of the process of correcting the measurement of surface phenomena for atmospheric effects. Thus, an accurate global elevation dataset is required in order to be quantitative about measurement of the land surface and for atmospheric measurement over the land. It is therefore important that we work toward the creation of as high a quality Global elevation data set as possible. Calibration and validation is perhaps the most important priority, in remote sensing missions of the present and future.

The geographic location of measurements is obviously critical in order to be able to compare successive measurements and to integrate them with other information in a GIS. This again requires a Digital Elevation Model. The accuracy and noise properties of such models is important to their use in the calibration and location of remote sensing measurements, however DEM accuracy is an area of research that is hardly touched.

Another important area of research is in database structures. Land management decisions as recently as a few decades ago involved little more than economic considerations, however today things are much different. Modern land management simultaneously requires data and information about social and environmental issues as well as the traditional economic ones. This requires huge amounts of diverse data. When one considers the problem from an operational viewpoint, the costs of rehosting 30 or more years of existing databases into modern form are enormous. A simple rehosting of this information is not a viable option from a cost point of view, let alone consideration of the errors that would be introduced in the process. We therefore have to find ways of achieving compatibility and universal access involving databases of vastly different structures and great diversity. Object orientation could be a fruitful area to explore in this regard.

Advanced Feature extraction is an area of research that knows no bounds. As the data volumes increase geometrically in the coming decades, the development of advanced feature extraction technology becomes ever more important, along with heavy requirements on calibration, validation and geolocation. If we are ever going to make use of the vast quantities of data that we will be capable of acquiring, we must develop the technology to screen and analyze the data automatically. In other words, we are going to have to create machines to sift through the data, recognize things that are important in a given context and present that information for human analysis. Any operational scheme that relies on humans looking at all the data is doomed to failure in an overwhelming sea of bits and bytes.

Data standards are absolutely vital to integration and exchange of information. However, from the integration viewpoint, we must not confuse data display and data representation. For this reason, I do not regard vector-to-raster and raster-to-vector conversion as an overly important issue. These are important in the display of information, but data can be represented in whatever form is appropriate and converted on the fly in the display process. Also, it must be remembered that we each possess a powerful carbon-based processor which can compensate for shortcomings in the display process. Visualization is an essential tool to enable wide band communication of concepts between a database representation and the human brain. In developing visualization technology and algorithms, we should not be hamstrung by our traditional 3-dimensional spatial view of the world.

#### **Questions and comments from the audience:**

- are there efforts in standardization? (Estes) Yes; however there is a clear need to implement some forms of standardization and then evolve. Current
- efforts perhaps overemphasize finding an optimum standard for the present time, rather than providing a framework which may then be tested by the users and then improved.
- Is it appropriate to create a single global database rather than implement distributed databases and exchange? (All) It is probably not possible to support the wide range of data and applications in this way.
- General discussion about the importance of examining political science and social science, since there are needs for a theory and tools for spatial information to support these disciplines.
- Observation from the audience: the European Science Foundation program in GIS has nothing about REMOTE SENSING/GIS integration. this perhaps reflects the limited scope and limited participation in the program.
- Observation from the audience: the care and manipulation of the data is as important as the gathering of the data, and historically the institutions responsible for collecting remote sensing observations have ignored this principle.