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SCIENCE RESEARCH**

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Abstract

This document is the final report summarizing research conducted by the Remote Sensing Research Unit, Department of Geography, University of California, Santa Barbara under National Aeronautics and Space Administration Research Grant NAG5-10457. This document describes work performed during the period of 1 March 2001 through 30 September 2002.

This report includes a survey of research proposed and performed within RSRU and the UCSB Geography Department during the past 25 years. A broad suite of RSRU research conducted under NAG5-10457 is also described under themes of Applied Research Activities and Information Science Research. This research includes:

- NASA ESA Research Grant Performance Metrics Reporting
- Global Data Set Thematic Accuracy Analysis
- ISCGM/Global Map Project Support
- Cooperative International Activities
- User Model Study of Global Environmental Data Sets
- Global Spatial Data Infrastructure
- CIESIN Collaboration
- On the Value of Coordinating Landsat Operations
- The California Marine Protected Areas Database: Compilation and Accuracy Issues
- Assessing Landslide Hazard Over a 130-Year Period for La Conchita, California
- Remote Sensing and Spatial Metrics for Applied Urban Area Analysis, including
 1. IKONOS Data Processing for Urban Analysis
 2. Image Segmentation and Object Oriented Classification
 3. Spectral Properties of Urban Materials
 4. Spatial Scale in Urban Mapping
 5. Variable Scale Spatial and Temporal Urban Growth Signatures
 6. Interpretation and Verification of SLEUTH Modeling Results
 7. Spatial Land Cover Pattern Analysis for Representing Urban Land Use and Socioeconomic Structures
- Colorado River Flood Plain Remote Sensing Study Support
- African Rainfall Modeling and Assessment
- Remote Sensing and GIS Integration

This document is submitted to:

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1. Introduction

This document is the final report summarizing research conducted by the Remote Sensing Research Unit, Department of Geography, University of California, Santa Barbara under National Aeronautics and Space Administration Research Grant NAG5-10457. NAG5-10457 is the last in a series of grants which have supported research in the UCSB Geography Department since the late 1970's. This document describes work performed during the period of 1 March 2001 through 30 September, 2002.

Since its inception in the mid-1970's, RSRU was directed by Dr. John E. Estes, Professor of Geography. With the death of Dr. Estes in 2001, Dr. Keith C. Clarke assumed the position of RSRU Director. Several research projects ongoing at the time of Dr. Estes' death have been brought to completion. The results of these projects, along with a number of new studies initiated during the past year, are described in this document.

In order to document the development of NASA-sponsored RSRU research, this report includes a summary of research proposed and performed within RSRU and the UCSB Geography Department during the past 25 years. This consists of project summaries, portions of proposed project plans and publication abstracts produced in RSRU since 1978. Each summary includes a list of principal project participants and publication authors as well as specific publication information and citations. Over time, ISRG/RSRU research was conducted under five principal NASA research grants: NSG-7220; NAGW-455; NAGW-1743; NAG5-3620; and NAG5-10457.

In addition to the historical survey of ISRG/RSRU research, this report also includes summaries of current RSRU research conducted under NAG5-10457. Applied research to develop and operate a system for compiling research grant performance metrics is described under the title of applied research. The rest of current RSRU research is summarized as information science research.

ISRG/RSRU research is conducted by faculty, research staff, and students at the University of California, Santa Barbara. In the past ISRG research has also been conducted with researchers at affiliated institutions and organizations. Over the past several years ISRG research has shifted to focus on improving our ability to employ advanced information systems with new spaceborne observation data. Particular focus was on Terra satellite sensor systems (formerly called EOS - the Earth Observing System) for basic, applied and commercially oriented research in the Earth Science Enterprise (ESE). The goal of our research continued to be the improvement of our understanding of the overall science and applications potential of ESE data and information products. During this period we paid close attention to data products produced by the Landsat 7 (ETM+) system that supports Earth science applications and the extended commercial remote sensing user community. ISRG/RSRU researchers have worked to accomplish this goal through research as well as fundamental and applied examination and evaluation of advanced information science techniques and methodologies.

Much of the research conducted under NAG5-10457 was collaborative in nature. Collaborative efforts initiated and conducted during previous years were partially supported from other sources. This type of "leveraged" funding and the additional research input and perspective into the research conducted under this grant have provided real benefit to NASA. During this final contract period, collaboration was undertaken with the following institutions and organizations:

- U.S. Geological Survey's Earth Resources Observation System (EROS) Data Center (EDC)
- Geographical Survey Institute (GSI) of the Ministry of Construction of Japan
- Digital Earth
- Global Spatial Data Infrastructure
- Globexplorer
- Global Initiatives, Inc.

Following this introduction, *Section 2* of this document presents a survey of past work accomplished in RSRU under NASA sponsorship. *Section 3* summarizes research and educational conducted in RSRU during the current reporting period, including applied research activities and information science research. Figures and Tables are numbered sequentially by subsection in this portion of the document. Performance metrics for this research program are summarized in *Section 4*. *Section 5* follows with a brief summary of the overall proposed effort. Finally, references cited in the proposal text, and current publications produced by ISRG researchers during the past year are found in *Sections 6*, and *7*, respectively.

1.1. Background

The world's population continues to increase. Along with this increase in global population, there is a continuing need for improved systems and techniques capable of acquiring, integrating, and analyzing information concerning the major components of the Earth's ecosystem. Parts of the ecosystem are cause for enormous concern. The general public and elected representatives continue to express concern over the status and trends of environmental indicators. There is increasing political and economic concern regarding the socioeconomic implications of both environmental preservation, and conservation. The demand is increasing for more accurate, up-to-date environmental information. The astute application of advanced remote sensing and information systems technology can help meet this critical demand.

Responding to this need, NASA Office of Earth Science (OES) Applications Commercialization and Education (ACE) Division is stressing the importance of understanding the Earth as a unique functioning biotic system. A key to achieving this understanding is the effective use of data and information from current and planned space based public and private civil satellite remote sensing programs. The use of such data and information can be facilitated by the expeditious development of advanced geospatial information systems, techniques and methodologies. These systems, and applications data and information products. If these products are to be utilized to their fullest potential, future geospatial information systems must be integrated with the National Information Infrastructure (NII - the national information superhighway), and the National Spatial Data Infrastructure (NSDI). In addition, these national geospatial information systems should fit seamlessly into the evolving Global Spatial Data Infrastructure (GSDI). This GSDI effort is central to the development of Digital Earth.

Data and information from Earth orbiting satellites and ground based data and information systems are critical as attempts are made to develop enlightened policies concerning the management of the Earth system. Previously, ISRG and affiliated personnel conducted more fundamental information

system related research in a number of specific areas and ISRG has been actively involved in education, support and coordination efforts related to this research.

In more recent efforts, a more applications-oriented approach has been the priority in order to demonstrate the transition from fundamental research to operational implementation. In these efforts, ISRG/RSRU personnel have been working with researchers at a number of institutions and organizations in the U.S. and abroad. These institutions and organizations include:

- University of Maryland, Baltimore County, MD
- Georgia Institute of Technology, Atlanta, GA
- Boston University, Boston, MA
- University of Virginia, Charlottesville, VA
- University of Idaho, Moscow, ID
- University of Maryland, College Park, MD
- University of Wisconsin, Madison, WI
- University of Florida, Gainesville, FL
- Consortium for International Earth Science Information Networks, New York, NY
- University of Bonn, Germany
- Friedrich Schiller University, Jena, Germany
- University of Osnabruck-Vechta, Vechta, Germany
- University of Padua, Italy
- Hiroshima Institute of Technology, Hiroshima, Japan
- Miyazaki University, Miyazaki, Japan
- United States department of Transportation, Washington, D.C.
- The U.S. Geological Survey EROS Data Center (USGS/EDC), Sioux Falls, SD
- NOAA Coastal Systems Center, Charleston, SC
- The Geographical Survey Institute of the Ministry of Construction of Japan,
- Australian Land Information Group, Canberra, Australia
- Joint Research Center, European Economic Community (JRC/ECE), Ispra, Italy
- CICESE, Ensenada, Mexico

For the current reporting period under this grant the focus has continued to be on fundamental, applications and commercially oriented research. Efforts have also been undertaken to determine which applied research topics are of greatest interest to the international remote sensing community.

Specific ongoing research topics include:

- The efforts around EOSDIS extension and user model development
- Operational and commercial applications of OES science data products
- Multi-scale, multi-temporal, multi-spectral image analysis for land management
- Multi-image registration
- Statistical processing and visualization of continental-scale climatic data
- Remote sensing / GIS integration for landform analysis and mapping

The results of ISRG/RSRU researcher are published regularly in reviewed journals and other publication outlets including symposia, conference, and workshop proceedings. ISRG personnel also make presentations at national and international scientific meetings. ISRG investigators have

also helped organize conferences, workshops, training courses and reviews. These have helped NASA Earth Science and education personnel and the international mapping, environment and development communities improve their data and information systems capabilities. In addition to these efforts, ISRG professors and researchers have also been working with other national and international organizations in examining macro-scale ecological and land cover issues.

1.2. Research Objectives

The fundamental objectives underlying ISRG/RSRU research during this reporting period were consistent with those of preceding NASA-sponsored research:

1. Improve understanding of public sector operational and commercial applications potential of Earth Science Enterprise (ESE) satellite remote sensing data and information.
2. Provide outreach to inform the Earth science remote sensing user community, environmental planners, resource managers, educators, public policy decision-makers and the general public of the basic and applied research and public sector and commercial potential of advance satellite remote sensor systems.
3. Facilitate the implementation of a broad-based remote sensing applications research program to the benefit of the applications user communities and the public at large, via research, education and outreach.

2. NASA – UCSB/RSRU Research – A Historical Perspective

2.1. Some Applications of Space Radars

D.S. Simonett (Ed.)

Appears in: *Summary Report for NASA Research Grant NAS-14816*
October, 1978

Since 1965, considerable research and funding has been devoted by the National Aeronautics and Space Administration, the Department of the Interior and other agencies, to estimating the costs and benefits of proposed and actual satellite earth resource survey systems. Some of these cost benefit studies have examined a number of applications, such as land use planning, flood warning, and mineral exploration, while others have focused upon a single function such as improved crop forecasting. A few studies have attempted to compare the economic merits of alternative data collection modes, e.g., aircraft vs. satellite based observation platforms but most have concentrated attention only on satellite systems. Despite considerable ingenuity and effort, many observers have expressed misgivings over the figures, particularly on benefits, obtained in these studies. That these misgivings are well founded is demonstrated by the very wide range of benefit estimates found in various studies for similar categories of use. For example, the range in recent estimates of the annual benefits to the U.S. arising from improved crop forecasting is from \$0.7 million to \$174 million. A number of studies have also resorted to cost-effectiveness analysis rather than cost benefit analysis because their authors hesitated to forecast future uses of imperfectly defined future products.

Cost-benefit analysis thus has much of the characteristics of a forecast with a high level of uncertainty. Since radar images are not yet in wide use by user agencies concerned with natural resources, the uncertainty will be further compounded. These considerations must be borne in mind in the following review of previous cost-benefit studies as we attempt to formulate ground rules for a future cost-benefit analysis of space imaging radars.

An idealized cost-benefit decision making process for sensor-derived information should include:

- 1) For each discipline or application the social value or worth of each information dimension should be identified and quantified for a hypothetical full access, error free radar image sensor;
- 2) Each maximum or optimal information value would then be modified downward by multiplicative coefficient summarizing the effectiveness of the sensing in providing useful output information;
- 3) The value or worth-effectiveness of the resulting information would be the potentially realizable social and technological benefits. These would be matched with costs and assembled in a cumulative, decreasing benefit-cost ratio.
- 4) Information value would be quantified through studies relating the social benefits of various improved information levels derived from space radar(s).

2.2. Forest Classification and Inventory System Using Landsat, Digital Terrain, and Ground Sample Data

A.H. Strahler, T. L. Logan, and Curtis E. Woodcock

Appears in: *Summary Report for NASA Research Grant NAS-15509*
April, 1979

A Landsat-based Forest Classification and Inventory System (FOCIS) is currently under development at the University of California at Santa Barbara (UCSB) and the Jet Propulsion Laboratory (JPL) of the California Institute of Technology at Pasadena (NASA contract number NAS-9-15509).

Incorporating Landsat images, digital terrain data, and ground sample plots, the primary goal of FOCIS is to produce volume estimates by area of sufficient accuracy for forest or forest-wide level planning purposes. Relying on automated processing of digital Landsat imagery, FOCIS will be more cost-effective and more consistent than conventional photo interpretation. In addition, inventories can be repeated at reduced incremental cost for annual updating or detection of changes produced by fire, clearing, logging, and other forest related activities.

The test area for FOCIS development is the Klamath National Forest. Located in northern California, this area includes 1,400 square miles of rugged terrain in the Siskiyou, Scott Bar, and Salmon Mountains. The topography ranges from 500 to 8000 feet in elevation and includes very little developed area. The high relief and mountainous topography provides a diversity of habitat that is reflected in the forest cover. At lower elevations, oak and other hardwoods of little commercial value are dominant.

2.3. Microwave/Thermal Infrared Soil Moisture Experiment, Santa Ynez Valley, California, 1980 Field Data Report

S.G. Atwater
C.E. Ezra

Appears in: *Summary Report for Jet Propulsion Laboratory Research Contract 955032*
October, 1980

This report presents the field verification data collected and the procedures used in support of an experiment entitled, "Microwave/Thermal Infrared Soil Moisture Experiment" sponsored by NASA/Jet Propulsion Laboratory's Earth and Space Sciences Division. The data were collected at an agricultural test site in the between May 5 and May 23, 1980. Collected coincident with passive microwave radiometer data, and micrometeorological data obtained by JPL, the field verification data quantified both soil moisture and temperature profiles as a function of time during a single drying cycle over four plots of different roughness. The data will be used to formulate a quantitative parameter whereby surface roughness variations can be accounted for in the soil moisture model. The data includes two separate sets of measurements:

1. Diurnal soil moisture and temperature data from Plot 1 (smooth) for use in a thermal inertia model using micro-meteorological inputs (IR data set); and,
2. Data taken coincident with the JPL microwave radiometer in each of the four plots (RAD data set).

The data presented includes the experiment sampling schedule, gravimetric soil moisture profile down to 30 cm for both the IR and RAD data sets, soil surface and subsurface temperature profile for the IR and RAD data sets down to 50 cm, graphical representations of the IR and RAD data sets, annotated field notes, and a complete soils analysis report.

2.4. Landsat Detection of Oil from Natural Seeps

M. Deutsch
J. E. Estes

Appears in: *Photogrammetric Engineering and Remote Sensing, Volume 46, Number 10.*
October 1980

Digital contrast-stretch enhancement showed the distribution of oil on the surface of the Santa Barbara Channel, California. Oil on the ocean surface from the natural seeps in the Santa Barbara Channel, California, could not be detected on frames of any of the four bands of standard Landsat positive or negative film transparencies, nor could the slicks be detected using digital scaling, density slicing, or ratioing techniques. Digital contrast-stretch enhancement, however, showed the distribution of oil on the surface. Aerial observations made within a few hours of the Landsat overpass confirmed the distribution of floating oil. The detection (on Landsat images) of floating oil from submarine seeps indicates a potentially valuable application for offshore oil exploration and environmental monitoring.

2.5. Remote Sensing Interface with Decision Systems

T. Streich

Appears in: *Summary Report for NASA Office of University Affairs Research Grant NSG-7220*
April, 1981

On October 8, 1979 the University of California at Santa Barbara, Geography Remote Sensing Unit, and the County of Santa Barbara entered into a cooperative project in order to study selected effects of a general plan amendment upon the County's rangeland economics. One task of this project encompassed evaluating a computerized environmental information system designed to allow County personnel to collect and manage a wide variety of data types including remotely sensed imagery. This report contains the University's evaluation of the environmental information system.

The author gratefully acknowledges support from the National Aeronautics and Space Administration (NASA) Office of University Affairs (NSG 7220), which was used to prepare this report. Development of the VICAR to EMIS interface was accomplished with funding from NASA/Ames (NAG 2-24). Finally, Santa Barbara County matched NASA funding for Department of Environmental Resources (DER) and Data Services personnel.

2.6. Watershed Runoff Study

F. Mertz

Appears in: *Summary Report for NASA Office of University Affairs Research Grant NSG-7220*
April, 1981

This research was conducted in cooperation with the Kern County Water Agency (KCWA), which provided field surveys, watershed calibration computations, and personnel man-hours. KCWA personnel will assist with future work including cluster labeling, field checking, error analysis, and model calibration for remote sensing derived inputs. In addition, KCWA personnel may utilize hardware and software at GRSU/UCSB for an information systems approach to runoff estimation. Analysis of the image processing techniques and runoff estimation procedures implemented in this research will follow.

2.7. Chamise Mapping

S. Atwater
M. Cosentino

Appears in: *Summary Report for NASA Office of University Affairs Research Grant NSG-7220*
April, 1981

Funded by National Aeronautics and Space Administration (NASA) Office of University Affairs (NSG 7220), the chamise mapping effort is conducted with close cooperation of the US Forest Service personnel of the Los Padres National Forest (LPNF). All vegetation history and siting data come from records held by the Forest Service. They established the parameters of this project by outlining their needs for chamise fuels information; i.e., age classes, slopes classes, etc. Additional support of the project has come in the form of two undergraduate student internships. These interns are expanding the fire history map to include all of Santa Barbara County and researching the annual phenology of chamise chaparral and its response disruption by fire and man. The basis for this project comes from work soon to be completed by Susan Atwater on the use of Landsat data to monitor seasonal changes in chamise moisture content.

2.8. Range Management Study

M. Cosentino
M. Boyle

Appears in: *Summary Report for NASA Office of University Affairs Research Grant NSG-7220*
April, 1981

Funding for this project is provided on a matching funds basis between the National Aeronautics and Space Administration (NASA) Office of University Affairs (NSG 7220) and Santa Barbara County Department of Environmental Resources (DER). Other cooperating agencies include University of California Cooperative Agricultural Extension Service, Santa Barbara County Executives Office, Santa Barbara County Planning Department, and Santa Barbara County Data Services. Resource management techniques such as those utilized in this project are being evaluated by DER for possible implementation in that agency's ongoing operations.

2.9. Perched Water Study

E. Ezra
L. Tinney

Appears in: *Summary Report for NASA Office of University Affairs Research Grant NSG-7220*
April, 1981

Drainage-related research during the past year, funded by National Aeronautics and Space Administration (NASA) Office of University Affairs (NSG 7220), was conducted in cooperation with the Kern County Water Agency (KCWA) and the Wheeler Ridge Water Storage District. These agencies provided depth-to-water table measurements and crop type information necessary for analysis of results from the Landsat remote sensing data used in this study. These agencies will continue to provide data to be used in further drainage assessment through Landsat remote sensing. Contacts with the US Salinity Lab at Riverside, California, have opened a new avenue of support. This group has provided, and will continue to provide, data from ongoing research in Lost Hills, California, concerning variable salinity contents and the effects on crop condition. The Lab is very much interested in any methodology using remote sensing whereby salinity sampling strategies could be improved (i.e., stratified sampling based upon apparent crop condition), and has agreed to work with our group on this project.

2.10. Cotton Mapping from Landsat Imagery

T. Torburn
L. Tinney

Appears in: *Summary Report for NASA Office of University Affairs Research Grant NSG-7220*
April, 1981

During the past three years, the Geography Remote Sensing Unit,(GRSU), University of California, Santa Barbara, has been involved in research related to the mapping of San Joaquin Valley cotton fields in support of the joint state and federal pink bollworm control program. The initial development and preliminary portion of this effort was funded as part of this grant (NSG 7220). Subsequent funding was provided through the NASA/Ames Consortium Agreement (NASA - Ames OR680-801) to incorporate historical Landsat data into the analyses and assess temporal reliability of the procedures. These demonstrations led to matching California Department of Food and Agriculture (CDFA) funds for a larger scale demonstration during the 1978 crop season (CDFA 7073). As part of our effort under this grant (National Aeronautics and Space Administration (NASA) Office of University Affairs (NSG 7220)) we have continued to coordinate and document these additional research efforts. The goal has been to develop an operational procedure suitable for implementation by CDFa and/or United States Department of Agriculture (USDA) personnel.

2.11. Analysis of Seasat-A SAR Data for the Detection of Oil on the Ocean Surface

J. E. Estes
M. Wilson
E.Hajic

Appears in: *Summary Report for NOAA Research Contract NA-79-SAC-00734*
October, 1980

In evaluating the capability of the Seasat-A Synthetic Aperture Radar to detect the smoothing effects of oil slicks on ocean surfaces, two problems were encountered. These were:

1. The lack of concurrent surface verification data, and
2. The appearance of so called confusion targets in the imagery.

To "synthesize" necessary surface truth information, a linear deterministic oil trajectory model has been developed which sums the effects of winds, currents, and tides to predict hourly oil slick configurations within the Santa Barbara Channel study area.

Using output oil slick trajectory predictions as a guide, a collection of 128 X 128 byte subimages was gathered from oil affected areas. Zones of reduced backscatter which could not be attributed to oil/surface tension effects (confusion targets) provided a similar set of subimages. Taking the two-dimensional Fourier transforms of these subimages and filtering via eight concentric ring masks allowed comparison of normalized mean power distribution as a function of

spatial frequency. These comparisons show a more rapid drop off in normalized power at higher frequency for oil slick images than for non-oil slick images. The optimum discriminant, of those tested, utilized the sum of normalized power from the six ring filters representing highest spatial frequency; Separation in this case was achieved at a 99 % confidence level.

2.12. Multispectral Determination of Soil Moisture

J.E. Estes
D.S. Simonett
E.J. Hajic
B. Blanchard

Appears in: *Summary Report for NASA Research Grant NCC-5-5*
December, 1980

The edited Guymon soil moisture data collected on August 2, 5, 14, 17, 1978 have been grouped into four field cover types for statistical analysis. These are the bare, milo with rows parallel to field of view, milo with rows perpendicular to field of view and alfalfa cover groups. There are 37, 22, 24 and 14 observations respectively in each group for each sensor channel and each soil moisture layer. A subset of these data called the 'five cover set' (VEG5) limited the scatterometer data to the 15° look angle. It was used to determine discriminant functions and combined group regressions. This data set was further edited to 21 bare field observations, and further separated the milo (viewed parallel to the rows) into milo drilled (8" height milo) and 2 1/2' to 3' high milo. The bare field editing was considered appropriate after comparing the regression slopes for each field on the 4 - day basis.

Summary graphs which combine selected analyses compare the effects of field cover. The overview continues with a comparison of stepwise regressions from the five group set with limited variables. The movement toward a soil moisture prediction algorithm more 'physically based' is represented by the result of a non-linear regression.

The analyses for each of the four cover types are presented principally in the form of graphs and tables with only brief commentary. Results of stepwise regressions are presented first as a cover type overview. The remaining sequence used is: elementary statistics, correlation matrix, single variable regressions, and factor analyses. Stepwise regressions are summarized in the sequence of the variable selected and the combined correlation coefficient. The regressions were determined primarily for SOIL02 as the dependent variable and used the highest correlating sensor channels of each sensor type.

Elementary statistics provide the mean, standard deviation and range of all variables. Correlation matrices were determined for the full set of variables. Significant correlations (at the .01 level of significance or better) and/or the highest correlating sensor types are summarized via tables of the intercepts and regression coefficients. Eigenvector and rotated factor analyses were determined for two variable sets for each cover type. These were: (1) a near full-variable set which thus shows the change in factor loadings as a function of the soil moisture layers, scatterometer look angles,

spectrometer channels and radiometer channels; and, (2) for the set of the highest correlating variables used in the stepwise regressions.

2.13. Knowledge-Based Expert Systems for Crop Identification

Terence R. Smith

John E. Estes

C. Sailer

L.R. Tinney

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
January, 1984

For the past year, UCSB has been conducting a cooperative study of the application of expert systems in the interpretation of digital remotely sensed imagery. Funding for this project was provided by the National Aeronautics and Space Administration the California Space Institute for the 1982-1983 fiscal year.

California Space Institute (Calspace) is a multicampus research unit of the University of California. Calspace funding represents "seed" money to support basic research in the space applications area. Research being conducted in this area is exploring the methodology and components of human image analysis in an agricultural applications area. The long term goal of this research effort is the development of an improved understanding of the interactive man-machine environment. In such an environment, as many feature inputs as practical would be automatically derived from a data-base and input into an expert system decision-making procedure. This procedure could then provide "expert" assistance to a trained image analyst to upgrade and improve the quantity and accuracy of the information extracted from the input data. The research being conducted for this project are the first steps towards this long-range goal.

To date, in this project, all aspects of the image interpretation process are being explored, beginning with the fundamental elements of the human image interpretation process. This is being done with the goal of achieving an improved understanding of these elements and their significance in the decision-making process. A comparison of the similarities and differences between manual and automated image interpretation techniques as currently practiced is also being explored. This effort is being accomplished to better understand current areas of overlap and to better define those intersections of human cognitive skill and machine technological capabilities wherein manual and automated procedures may eventually meet.

Several papers have already been generated from this work. These papers were presented at the 17th International Remote Sensing Symposium at Ann Arbor, Michigan at the National Telecommunications Conference in San Francisco, California. In addition to these papers a number of preliminary experiments have been conducted. These experiments involved sessions where image analysts were shown two sets of multi-date LANDSAT imagery, and a set of LANDSAT images of predominately agricultural areas which exhibited varied agricultural practices.

2.14. Boreal Forest Vegetation Analysis, Ely, Minnesota

D.B. Botkin
K.D. Hoods

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
May, 1984

The work accomplished during 1983 under the funds from the NASA Office of University Affairs was part of a larger study titled "Habitability of the Earth: Analysis of Key Vegetation Factors." The general purposes of this research are (1) to develop and test methods to measure land vegetation biomass, net biological production and leaf area index by remote sensing; and (2) to apply these measures to estimate the biomass and net biological productivity of selected biomes, including the boreal forests and north temperate grasslands. Under funds from the NASA Office of University Affairs field verification was conducted in conjunction with remote sensing of pertinent variables and the development of a data base of relevant material initiated. Specifically, measurements were made in the Superior National Forest, Minnesota on those vegetation characteristics which are being correlated with the following remote sensing measurements: (a) an 8-band Barnes radiometer mounted in a helicopter which hovered at 400 feet above each site; (b) the thematic mapper simulator flown in a NASA C-130 aircraft; (c) MSS data from Landsat 3; and (d) AVHRR data from the NOAA Satellite.

2.15. Large Area Vegetation Mapping

J.E. Estes
J.L. Star
L. Mann
M. Cosentino
D. Eckhardt
S. Yool

Appears in: *Annual Summary Report for NASA Research Grant NAGW-45*
5January, 1985

Available maps of vegetation at global scales are both too inaccurate and far too general to provide a basis to answer major questions concerning biogeochemistry. An example of such a major question concerns the influence of deforestation on the release of carbon into the atmosphere.

In order to understand and monitor the role vegetation plays in the carbon cycle, scientists need maps of vegetation produced from timely, synoptic surveys of the Earth's surface. This paper

describes ongoing research on the feasibility of producing such a map for the North American Boreal Forest (NABF) from spaceborne sensor data. The boreal forest was chosen for study because it contains an estimated one sixth of the Earth's terrestrial carbon, yet is a relatively simple ecosystem conducive to environmental modeling. This work is being conducted at the Remote Sensing Research Unit of the University of California at Santa Barbara (UCSB) in conjunction with the Earth Sciences and Applications Division of NASA's Johnson Space Center (JSC).

Due to the large area extent of the NABF, minimization of data acquisition, processing and storage costs are necessary, as is frequent repeat coverage to ensure cloud free imagery for all areas of the NABF. The Advanced Very High Resolution Radiometer (AVHRR) sensors aboard the National Oceanographic and Atmospheric Agency (NOAA) 6, 7, and 8 satellites are an obvious choice to provide data for the first stage in a multi-stage sampling and inference strategy. Ultimately, AVHRR data will be used along with higher spatial resolution data (Landsat Multispectral Scanner - MSS, Thematic Mapper - TM, aerial photography, and in situ) for defining land cover. This document describes the procedures used to evaluate the utility of manually interpreted Landsat MSS data as one step towards this goal.

We view the entire process of integrating disparate data types as the creation of a particular kind of database, which necessitates a specific kind of information system. We are working with data sources of different spatial, spectral, and temporal characteristics. All this data carries information about the earth's surface. From our point of view, we are working in a geographic information system context, where the key inter-comparison between the data sources is geographic location. In doing so, we are using individual data planes and combinations of data planes, to test concepts as well as techniques. Our long-range objective is to improve the type and quality of information extractable from remotely sensed data.

2.16. Biomass Ground Truth: Assessing Key Vegetation Characteristics

D.B. Botkin
K. Woods

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
January, 1985

Support of field work to acquire ground-truth data for the study "Global Habitability: Assessing Key Vegetation Characteristics" is a continuation of the work undertaken in 1983. Principal Investigators for this project were J. E. Estes and D. B. Botkin at University of California, Santa Barbara, and R. MacDonald at Johnson Space Center. Other aspects of the study were supported through a cooperative agreement between JSC and UCSB.

The overall goal of this research is to contribute to the measurement of the global biomass and net primary productivity in a program of assessing the continued habitability of the earth. Our intention is to demonstrate the validity of using remote sensing to monitor vegetation characteristics by measuring biomass, productivity, and leaf area for specific regions of boreal forest, with an error of less than 20%.

Our approach includes the development and calibrating of models that relate vegetation characteristics to remote sensing data. In this work we use our understanding of physical relationships and appropriate statistical procedures to develop models relating biomass and productivity to leaf area indices, and leaf area indices to remotely-sensed spectral images. This requires (1) accurate ground measurement of vegetation characteristics, (2) acquisition of remotely-sensed data for measured sites, and (3) study canopy reflectance models and statistical models.

North American boreal forests were chosen as an appropriate system in which to first approach this work. We chose as an initial study area the Superior National Forest (SNF) near Ely, Minn. This site was chosen because, (1) it is one of several areas where boreal forest extends into the coterminous United States, (2) it is relatively well studied already, (3) necessary facilities were available, and (4) it had an appropriate range of vegetation and topography for an initial study site.

Following choice of the study area, study plots for concentrated attention were established during reconnaissance trips in spring of 1983 by, first stratifying the vegetation into distinctive forest types, based on published reports, second, choosing strata of particular interest, and, third, locating plots in stands of chosen types to represent the full range of leaf area, biomass, etc. of those strata. Field crews studied these through acquisition of spectral data from helicopters and aircraft flying at various altitudes and intensive direct measurements of biophysical parameters.

2.17. Advanced Data Structures and Geographic Information Systems

D.J. Pequet

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
May, 1985

Large integrated software systems known as Geobased or Geographic Information Systems (GIS) have been developed in the past fifteen years which can perform all phases of storage, maintenance, analysis and retrieval for geographic data. GIS' based on shared, large-scale, integrated data bases are used for a wide range of applications which deal with geographic data for government agencies and private corporations worldwide. They have already become an indispensable tool for managing biophysical, biological, and socio-economic data in a timely and efficient manner. However, only a limited volume and range of data types can be handled by any one system at a given time using present GIS technology. Overcoming these two problems are critical for the analysis of complex environmental problems if we are to successfully manage our resources on local, regional, and global scales.

The purpose of this project is to begin to examine the current state of the art in specified areas of GIS technology and to establish common ground for research. Study of the question of very large,

efficient, heterogeneous spatial databases is required as NASA begins to explore the potential application of remotely sensed data for studying the long term habitability of the earth.

2.18. Coordinating Hazardous Waste Management Activities Using Geographic Information Systems

J.E. Estes
K.C. McGwire
G.A. Fletcher
T.W. Foresman

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
January, 1986

This paper describes a framework for the role of geographic information systems (GIS's) in the monitoring and management of hazardous waste sites. Compilation of required information, incorporation of existing waste monitoring strategies, analysis of these data in a GIS environment, and the integration of computerized models for transport processes are discussed. Examples for the analysis of spatial data using cartographic overlay techniques and the implementation of geo-statistical methods on monitoring data are provided from work in progress by the authors. These examples are set in the context of developing a fully integrated monitoring and management system utilizing GIS technology.

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2.20. Interpolation and Uncertainty in GIS Modeling

K.C. McGwire
J.E. Estes

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
January, 1986

This paper discusses the incorporation of data taken from point samples with area covering data types found in a geographic information systems (GIS). The authors provide examples for two methods of interpolating point data to area covering surfaces and statistical methods for characterizing error for these surfaces. The moving averages technique of interpolation is found to be computationally efficient, however, establishment of optimal interpolation parameters is difficult and only a simple error statistic can be generated for GIS data layers created using this method. Kriging, a geostatistical technique, is a more demanding method for interpolation of surfaces and may be appropriate for certain environmental variables. Kriging is shown to provide valuable estimations of error throughout the surfaced data layer, reflecting spatial positioning of samples and variance observed in those samples. Techniques for the estimation of error in GIS data layers, such as those discussed in this paper, must be implemented in operational GIS's in order to provide information products and confidence measures that will form the basis for effective decision making with spatial data.

2.21. Evaluation of Thematic Mapper Simulator Data for Commercialization and Time Dynamics

L.J. Mann
C.T. Sailer
J.E. Estes

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
January, 1986

This report summarizes research evaluating Thematic Mapper Simulator (TMS) data for an improved understanding of the potential commercial agricultural applications. The thrust of the research was to examine processing techniques and improved information potential available from multispectral data acquired with high temporal frequency. Such work will be valuable in analyzing the overall high resolution imaging system which is planned as part of the Earth Observing System (EOS) sensor compliment (e.g. High Resolution Imaging Spectrometer (HIR.S)).

Our approach in this research was to examine the TMS data for two diverse and highly productive agricultural areas in southern and central California. Supervised and unsupervised classifications were performed and evaluated in an effort to monitor change through time of the agricultural crops in the study site. The information potential inherent in the temporal dimension of TMS data was addressed in this study to examine agricultural management issues which arise during farm operations. The commercialization aspect of the study was addressed by identifying the potential market for data of this type, the market's data frequency requirements, and anticipated product needs. Product need was examined both from a hardware and software standpoint, with emphasis placed on remote sensing data products.

TMS data used in this evaluation was simulated by a Daedalus 074 high-altitude multispectral scanner flown on a U-2 and ER-2 aircraft at an approximate altitude of 65,000 ft. above ground datum. The Daedalus system has an IFOV of 1.3 mr and a ground resolution of 28m.

2.22. Evaluation of Thematic Mapper Simulator Data for Commercial Application to Natural Vegetation of Southern California

M. Cosentino
J. Estes

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
March, 1986

This report briefly summarizes an evaluation of Thematic Mapper Simulator (TMS) data for commercial application to natural vegetation of southern California. The approach was to examine the TMS data for several dates (7/2, 8/6, 9/17) over the same area and to determine whether phenological changes in natural vegetation could be detected. Species discrimination within the chaparral brush stands of southern California has typically been extremely difficult using 80m resolution MSS data. Stands of one type of green shrubs are very difficult to discriminate from another type of green shrubs using 80m resolution data. The increased spatial and spectral resolution of TMS data, coupled with knowledge of phenological cycles of natural vegetation, could provide new and valuable data concerning the spatial distribution of key vegetation species.

The temporal sequence of TMS data for this study was acquired during a period (July - September) when the flowering heads of the chamise plant (*Adenostoma fasciculatum*) began to dry and harden and turn a distinctive red/brown. Chamise is an important chaparral species with a broad range over all of California. Spectral discrimination of the spatial distribution of stands of chamise would be highly desirable for a number of forest land applications including: fire control, fuel management, range management, and wildlife management. Likewise, the potential exists to identify other important chaparral species in the same manner.

Upon examination of the TMS data for the phenology study site, it was determined that the July TMS data was of excellent quality and provided a good baseline of data for the phenology study.

2.23. Neotectonics of the San Andreas Fault System - Basin and Range Province Juncture

J.E. Estes

J.C. Crowell
R.E. Crippen

Appears in: *Summary Technical Report for NASA Research Grant NAG5-177*
March, 1986

This final report briefly summarizes research at the University of California, Santa Barbara, on National Aeronautics and Space Administration Grant NAG 5-177. As part of the NASA Geodynamics Program, the general objective of our study has been an improved understanding of the tectonic interplay of the southern San Andreas Fault system and the Basin and Range province in the vicinity of the Eastern Transverse Ranges of Southern California.

A parallel objective has been to determine the utility of remotely sensed imagery and other spatial data in the analysis of neotectonic patterns. A wide variety of techniques, some standard and some experimental, have been used and it is believed that the findings of this research will be of value both to the earth scientist interested in our study site and to others who might beneficially apply some of the methodologies developed here to other sites.

2.24. Detection of Subsurface Features in SEASAT Radar Images of Means Valley, Mojave Desert, California

R.G. Blom
R.E. Crippen
C. Elachi

Appears in: *Summary Technical Report for NASA Research Grant NAG5-177*
March, 1986

Igneous dikes buried beneath as much as 2 m of alluvium in the Mojave Desert of California were detected by the SEASAT L-band (23.5-cm wavelength) synthetic aperture radar (SAR) in 1978. The roughness and dihedral configuration of the dikes are favorable to generation of strong radar echoes. The soil-moisture levels in 1978 were likely below the critical 146 level. The other permissive conditions for radar penetration of a fine-grained and thin alluvial cover are present. Our findings suggest that subsurface features with potential tectonic or geomorphic significance may be revealed in other orbital radar images of semiarid terrains.

2.25. Performance Analysis of Image Processing Algorithms for Classification of Natural Vegetation in the Mountains of Southern California

S.R. Yool
J.L. Star
J.E. Estes
D.B. Botkin
D.W. Eckhardt
F.W. Davis

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
May, 1986

The Earth's forests fix carbon from the atmosphere during photosynthesis. Scientists are concerned that massive forest removals may promote an increase in atmospheric carbon dioxide, with possible global warming and related environmental effects. Space-based remote sensing may enable the production of accurate world forest maps needed to examine this concern objectively. To test the limits of remote sensing for large-area forest mapping, we use LANDSAT data acquired over a site in the forested mountains of southern California to examine the relative capacities of a variety of popular image processing algorithms to discriminate different forest types. Results indicate that certain algorithms are best suited to forest classification. Differences in performance between the algorithms tested appear related to variations in their sensitivities to spectral variations caused by background reflectance, differential illumination, and spatial pattern by species. Results emphasize the complexity between the land-cover regime, remotely sensed data and the algorithms used to process these data.

2.26. Requirements and Principles for the Implementation and Construction of Large-Scale Geographic Information Systems

Terence R. Smith
Sudhakar Menon
Jeffrey L. Star
John E. Estes

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
January, 1987

This paper provides a brief survey of the history, structure and functions of 'traditional' geographic information systems (GIS), and then suggests a set of requirements that large-scale GIS should satisfy, together with a set of principles for their satisfaction. These principles, which include the systematic application of techniques from several sub-fields of computer science to the design and implementation of GIS and the integration of techniques from computer vision and image processing into standard GIS technology, are discussed in some detail. In particular, the paper provides a detailed discussion of questions relating to appropriate data models, data structures and computational procedures for the efficient storage, retrieval and analysis of spatially-indexed data

2.27. The Regression Intersection Method of Adjusting Image Data for Band Ratioing

R.E. Crippen

Appears in: *International Journal of Remote Sensing, Volume 8, Number 2.*
June, 1987

Estimation of the combined path radiance and sensor offset terms is essential in adjusting multispectral image radiance measurements for band ratioing. Commonly applied techniques for making this estimate have required assumptions or ancillary information regarding the reflectance properties of surface materials. This paper presents a technique that is unique in that it provides absolute (not just relative) statistically-derived estimates without the use of ancillary information. It is termed the regression intersection method (RIM). RIM is based on contrasts between the spectral properties of various homogeneous areas in rugged terrain. These areas are selected by examination of the image data alone. Bispectral regression (first principal component) lines are determined for each area and are projected, in pairs, to intersection points. Ideally, the coordinates of these points must equal the measurements for zero ground radiance since that is the only condition under which spectrally different materials can have the same radiance values. The median result from several site-pair and band-pair comparisons is used in order to statistically mitigate noise and minor variations due to natural variability. Tests show that the method is successful in determining correction values for the image data that result in maximum removal of the topographic effect in ratio images.

2.28. Browse of Remotely Sensed Data

J.E. Estes
J.L. Star

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
January, 1989

We are in the midst of a several year research and development effort, titled "Browse in the EOS Era", funded through grant NASA NAGW-987. This project is based on developing a computer software testbed, through which we may examine different approaches to the problem of making remotely sensed science data available to the users. The issue specifically regards one of the key problems in science data management. This becomes an extremely important issue as we begin to prepare for the 1990's and EOS, with its extraordinary capabilities for multi-sensor data collection. This effort results from the discussions at and recommendations made by the ESADS meeting and EOS Data Panel reports.

A number of scientists are working with us to use our testbed, as well as contribute datasets and ideas to our staff. Collaborators outside of the University of California, Santa Barbara include

researchers at Georgia Tech, Purdue University, San Diego State University, the University of Alaska, University of California at Berkeley, University of Colorado at Boulder, University of Rhode Island, and the University of South Carolina, as well as staff at NASA Ames Research Center and the Jet Propulsion Laboratory.

During the first year of this effort, we constructed a software testbed, in which a number of our ideas on spatial data management may be exercised. A key goal of the second year has been to keep the testbed in operation, adding new datasets and users, to compile the user requirements discussed in the original proposal. Operating the testbed, including connections to appropriate nationwide networks, has been a primary task.

Accomplishments in the last six months included a number of planned optimizations to the current testbed for the second year. These included refinements in the user interface, a better-developed session history mechanism, and a revised electronic map model, based on a hierarchical data structure. In particular, the electronic map was reworked, to reflect (1) a better understanding of user needs and network throughput capabilities, and (2) a locally developed hierarchical data structure. Elements of all these components are now implemented.

In the coming grant period, we have plans to investigate several new areas. These include distributed heterogeneous database query, 'intelligence' in a user interface to spatial datasets, and optimal compression of browse data. Distributed query involves moving the user's request from one database system on one computer to a different database system on another computer with a different operating system. Such an experiment is a reasonable model to the distributed archives in NASA, NOAA, USGS, and many universities, where database managers and operating systems are not standardized.

2.29. National Center for Geographic Information and Analysis

J.L. Star
J.E. Estes

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
January, 1989

The National Center for Geographic Information and Analysis is organized around four distinct units: the administrative center located at the University of California, Santa Barbara, and the three research and education centers at Santa Barbara, the State University of New York at Buffalo, and the University of Maine at Orono. The focus of the center has clear overlaps with that of our ISRG research program.

Research in the National Center will be undertaken by means of initiatives, designed to fully investigate impediments to the more widespread implementation of geographic information systems. A research initiative typically consists of a specialist meeting, working groups undertaking intensive research, in-progress seminars, and a national or international conference to present results.

Publications of various kinds will result from the initiative process. Twelve initiatives have been defined; and the first two have already begun:

1. Accuracy of Spatial Databases
2. Languages of Spatial Relations
3. Multiple Representations
4. Use and Value of Geographic Information in Decision Making
5. Architecture of Very Large GIS Databases
6. Spatial Decision Support Systems
7. Visualization of the Quality of Spatial Information
8. Expert Systems for Cartographic Design
9. Institutions Sharing Spatial Information
10. Temporal Relations in GIS
11. Space-Time Statistical Models in GIS
12. Remote Sensing and GIS

In addition, there is a commitment within the National Center to education. The National Center's education program will attack the issue along three different fronts:

- Education of undergraduate, graduate, and post-graduate students at the three NCGIA institutions
- Introduction of GIS-related courses in local high schools
- Education of undergraduate and graduate students enrolled at other institutions;
- Extensive workshops, summer seminars, conferences, educational publications, and related outreach activities for the GIS community.

2.30. California Condor Habitat Database Project

J. Scepan

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
January, 1989

A large-scale research and management effort involving public agencies and private groups is ongoing to restore the population of the highly endangered California Condor (*Gymnogyps californianus*). The goal of this program is to establish a viable population of 100 free-ranging condors (including 60 breeding adults) within the historic range of the species in California. A program of captive breeding has been instituted to increase the species population and the remaining 29 condors are currently in captivity.

Environmental analysis of the historic range of the condor within California is a critical component of the overall recovery program. ISRG staff are currently in the second year of a cooperative research program to construct an operational Geographic Information System (GIS) which will cover the entire 2.4 million hectare historic range of the California condor. Other agencies which are contributing to this effort are the California Department of Fish and Game, and the University of

California, Santa Barbara Academic Senate; the Audubon Society is also involved in this project, and we have had early discussions with federal agencies as well. This environmental database system will be used in identifying that portion of the historic range which remains as suitable condor habitat within California.

An initial pilot GIS was compiled at UCSB in order to examine basic research issues and as preliminary test of image processing and GIS techniques. Current ongoing cooperative condor habitat research is focused on several specific tasks. We are completing a digital land use and land cover database layer for the 2.4 million hectare study area. This database comes from both remote sensing and conventional map products, which we are interpreting and compiling with a commercial GIS product. We are also combining condor observation data with this land use and land cover dataset and with digital topographic data to examine issues of map scale, resolution, classification and accuracy. Projected uses of this GIS for multispecies analysis and species richness mapping is also being evaluated.

The results of our initial work demonstrate that a geographic information system is an efficient and effective tool for compiling and analyzing the large amount of disparate environmental data that is relevant to condor habitat. An interactive, relational GIS is the only method currently available that can be used for predictive habitat modeling for the condor and for other rare, threatened and endangered species within California.

2.31. Agricultural Monitoring and Econometric Modeling in an Information Systems Context for the Regione del Veneto, Italy

J. Scepan

Appears in: *Annual Summary Report for NASA Research Grant NAGW-455*
January, 1989

The Regione del Veneto has instituted a cooperative research program with the University of California with the goal to develop regional scale crop determination procedures and production and yield estimation techniques to support agricultural resource management. This project is a part of an integrated environmental monitoring program being implemented for the Regione. Accurate crop yield prediction capabilities can increase the efficiency of agriculture in the Regione as well provide useful environmental data on the use of water resources and the use of chemical fertilizers and pesticides. Accurate, systematic crop inventory and yield and production estimation techniques are being developed for six principal crops grown within the Regione: small grains (wheat and barley), soybeans, sugar beets, corn, vineyards and orchards. UCSB's ISRG funding has provided matching funds for this work, mainly through the funding of graduate students and their M.A. thesis research projects.

Developing a system of crop inventory in this area presents some particular challenges. The Regione del Veneto contains an extremely complex mix of land uses and land covers. In addition, agricultural production in the Regione is characterized by small field sizes, a diverse crop mix and multiple cropping in some areas. Due this particular type of land use complexity, work to date has focused on

developing digital techniques for removal of non-agricultural areas from the spectral data used for crop identification. This process of image "masking" has proven to be an effective data reduction algorithm in image classification. Work has also progressed in multirate image classification using image ratios and selective band transformations. This image classification work was concentrated on eight test sites distributed through the Region's lower and middle plain area (in which major crop production is concentrated). Agrometeorological crop yield modeling continues to be evaluated for utility in this project and selected datasets have been compiled and processed as a part of this analysis.

Work in the past year in this study has demonstrated that both crop identification and crop yield modeling are data dependent. Accurate crop identification requires careful selection and timely acquisition of satellite data. Agrometeorological based crop yield modeling is dependent upon complete and accurate historical yield and weather datasets.

2.32. Image Processing Techniques for Crop-Type Identification in the Regione Del Veneto, Italy

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J. Scepan
J.E. Estes

Appears in: *Annual Summary Report for NASA Research Grant NAGW-1743*
January, 1990

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The Regione den Veneto (Italy) is cooperating with the University of California, Santa Barbara (U.S.A.) to develop a system of econometric crop production. A critical part of the crop yield modeling process is the identification of crops using multispectral satellite data. Five crops are to be included in this project; small grains (wheat and barley), corn, sugar beets, soybeans, orchards and vineyards. This paper explores two strategies to improve crop type classification: (1) use of ancillary data stored in digital format and (2) use of multi-temporal data. Ancillary information stored on digital files were used in this research to remove (mask) non-agricultural areas form satellite image data. Comparison between the classification of masked and unmasked images showed that improvement ranged from 3% to 26% depending on crop type. The multi-date approach to classification was created by compiling transformed spectral bands and TM-5 bands. The transformed bands were TM band 4 over TM band3.

2.33. WETNET: An EOS Prototype Experiment

J.L. Star

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January, 1991

WetNet was conceived as a multi-year pilot program to examine and exercise interactive networked computing facilities as a working environment for earth science research. Access to the networked facilities is via a workstation at the investigator's institution (PS/2-70 class machine running the McIDAS software). The datasets of particular interest to the program include DMSP SSM/I and NOAA AVHRR. The overall program is designed to evaluate various modes for the rapid delivery of science data and derived products to a geographically distributed science team, and to facilitate interdisciplinary earth science.

UCSB's participation in the past year has included work on the project executive committee, as well as preliminary use of PS/2-McIDAS and background research. In our 1990 calendar year proposal to MSFC, we proposed to continue to work with the project management team, as well as (1) begin an earth science research experiment, and (2) assist in the continued development of McIDAS as a research tool. The latter activity involves database and interface work on the McIDAS workstation, as well as participation in user training.

Our earth science research within the WETNET program is based on the potential of SSM/I to provide large area, frequent revisit information about land vegetation. Numerous studies have been made utilizing the coarse resolution of the Advanced Very High Resolution Radiometer (AVHRR) sensor onboard NOAA satellites of the TIROS-N series for analysis of vegetation at regional or continental scales. These studies have primarily focused on the normalized difference vegetation index, a data product derived from a normalized ratio of reflectance measured in near-infrared and red wavelengths. Studies of NDVI have included both qualitative descriptions of its correspondence with phenological patterns and quantitative relationships between NDVI and field measured biomass.

Estimations of vegetative productivity on a global scale are being sought both in terms of a need to monitor sensitive environments and as an input to models of climate and carbon cycling. Data volumes for continental or global studies become prohibitive at resolutions greater than the 1.1 kilometer resolution of the AVHRR sensor. In addition, current climate models are generally not parameterized beyond the 0.5 to 1.0 degree resolution in latitude/longitude. Thus, remote sensing systems with coarse spatial resolution and high temporal frequency are being investigated for their utility in quantitatively monitoring global vegetation.

2.34. Extracting Agricultural Information from Satellite Imagery for Mapping Purposes

D. Ehrlich
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J. Scepan

Appears in: *Annual Summary Report for NASA Research Grant NAGW-1743*
January, 1991

This paper describes the development and testing of new approaches to computer-assisted image analysis for agricultural surveys. The study area for the research being conducted is located in Northern Italy (Regione del Veneto). The study area is characterized by small field agricultural areas interspersed with non-barren areas. The research is being conducted as part of a crop inventory project which aims at producing crop type maps for each growing season from satellite imagery.

Satellite imagery collected from land resource satellites have shown potential for land-use land-cover classification and map production. Human-assisted classification procedures have shown to be accurate but may not be adequate for frequent monitoring of the earth as required in crop inventories. Computer assisted classification techniques on the other hand allow the processing of imagery at high speed but currently lack the accuracy required for most operational agricultural needs.

Semi-automatic and automatic classification procedures using multi-temporal imagery developed in this project are evaluated and tested. Preliminary results of the classification of the five crop types under investigation show results accuracies ranging from 70 % to 96 %. Classification results obtained from processing satellite imagery will be input in a vector based GIS. The sophisticated capabilities of the GIS will be used to produce a map product which will be used by resource managers in the Regione del Veneto.

2.35. Sensitivity of Habitat Models to Uncertainties in GIS Data: A California Condor Case Study

D.M. Stoms
F.W. Davis
C.B. Cogan
M.O. Painho
B.W. Duncan
J. Scepan

Appears in: *Annual Summary Report for NASA Research Grant NAGW-1743*
January, 1991

Spatial decision makers need to know the reliability of the output products from GIS analysis. For many GIS applications, however, it is not possible to compare these products to an independent

measure of "truth". Sensitivity analysis offers an alternative means of estimating reliability. In this paper, we present a GIS-based statistical procedure for measuring the sensitivity of wildlife habitat models to data quality and model assumptions. The approach is demonstrated in an analysis of habitat associations derived from a GIS database of the distribution and habitat of the endangered California condor. Alternative data sets are generated to compare results over a reasonable range of assumptions about the nature of uncertainty from three sources. Sensitivity analysis indicated that condor habitat associations are relatively robust and thus has increased our confidence in our initial findings. Methods described in the paper should have general relevance for many GIS applications.

2.36. A Geographic Information Systems Approach to Mapping Protected Areas for North America

K. Beardsley
J.L. Star
J.E. Estes

Appears in: *Annual Summary Report for NASA Research Grant NAGW-1743*
January, 1992

As concern over the current rapid decline in species and biological diversity increases, an urgent demand for information on the spatial location and areal extent of protected areas has emerged. In response to this emerging need, development of a digital protected areas map has begun. In order to expedite the production of a Geographic Information System (GIS) protected areas coverage for the North American continent, University of California, Santa Barbara researchers are compiling a digital protected areas map of North America in conjunction with WCMC and UNEP/GRID. Production of this map involves gathering information from a variety of government agencies and private organizations, combining these various data sources into a set of GIS coverages, assessing the levels of protection provided for each area, and linking the GIS boundary polygons with WCMC's database, which contains detailed attribute information for each protected area. Through our extensive search for existing data of protected area boundaries in North America we have discovered that surprisingly little information exists, despite the high demand level indicated for such GIS coverage. For many applications, including land use planning, biological diversity assessment and endangered species preservation, a comprehensive digital map of all biologically reserved areas in North America is essential. Once this product is assembled for North America and combined with the GIS protected area coverages being produced at WCMC, we can begin to assess the level of protection offered to species at the global level, to better determine which species are adequately protected, and to identify which may require greater levels of protection in order to ensure their survival.

2.37. Multitemporal Multispectral Observations of Natural Vegetation

J. Star
T. S. Henderson

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January, 1992

A multitemporal normalized difference vegetation index, NDVI, was created from AVHRR composite images and compared to four sites in Southern California. The object was to compare the data from these sites with the microwave vegetation index, MVI, produced from SSM/I passive microwave data. The size of the derived NDVI pixels is 1km^2 and the SSM/I pixels is 625km^2 . A grid of 25 pixels on a side of the NDVI data was produced with nested subsets of 3×3 , 5×5 , 10×10 , and 25×25 pixels to determine the multitemporal trajectory of the NDVI across increasingly heterogeneous sites. Nonparametric methods were used to evaluate the correlation within the nested subsets. Correlations between the 3×3 and 25×25 pixel sets ranged from 0.889 in a chaparral/grassland site to 0.560 in a white target invariant (Rogers Dry Lake) site.

2.38. Geographic Analysis of California Condor Habitat Sighting Data

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M.O. Painho
B.W. Duncan
J. Scepan

Appears in: *Annual Summary Report for NASA Research Grant NAGW-1743*
January, 1992

Observation and habitat data were compiled and analyzed in conjunction with recovery planning for the endangered California condor (*Gymnogyps californianus*). A GIS was used to provide a quantitative inventory of recent historical condor habitats, to measure the association of condor activity patterns and mapped habitat variables, and to examine spatio-temporal changes in the range of the species during its decline. Only five percent of the study area within the historic range is now used for urban or cultivated agricultural purposes. Observations of condor feeding, perching, and nesting were nonrandomly associated with mapped land cover, in agreement with life history information for the species. The precipitous decline in numbers of condors in this century produced only a small reduction in the limits of the observed species' range, as individual birds continued to forage over most of the range. Some critical risk factors such as shooting and lead poisoning are difficult to map and have not been included in the database. Besides the applications demonstrated in this case study, GIS can be a valuable tool for recovery planning, in the design of stratified sampling schemes, or extrapolation of habitat models over unsurveyed regions. We conclude with

recommendations from this case study regarding when to consider using GIS and the importance of pilot studies and sensitivity analysis.

2.39. A Remote Sensing Research Agenda for Mapping and Monitoring Biodiversity

D.M. Stoms
J.E. Estes

Appears in: *Annual Summary Report for NASA Research Grant NAGW-1743*
January, 1992

There is an urgent need to inventory and monitor indicators of biological diversity, such as species richness. Remotely sensed data provides a means to accomplish part of this task, but there has been no comprehensive scientific framework to guide its effective application. Here we propose a remote sensing research agenda designed to improve the quality and quantity of information available for conservation planning, monitoring, and testing scientific hypotheses. Biodiversity should be more fully incorporated into ongoing earth system science and global change programs, with remote sensing featured as a prominent data acquisition and analysis tool.

2.40. Applications of NOAA-AVHRR 1 Km Data for Environmental Monitoring

D. Ehrlich
J. E. Estes
A. Singh

Appears in: *International Journal of Remote Sensing, Volume 15, Number 1.*
February, 1994

This paper reviews the applications of NOAA-AVHRR 1 km data for environmental monitoring. This topic is very significant in view of the development of 1 km global datasets. Research papers reviewed herein largely describe application of AVHRR data for North America, Sahelian Africa and tropical forests of both Africa and South America. All 5 AVHRR bands have found some level of use for land-cover studies. However, the majority of the land characterization research papers used AVHRR/NDVI as the main data source. Multitemporal NDVI datasets have found wide use to describe vegetation phenology. AVHRR thermal bands have also been employed by a number of researchers for both surface temperature mapping and for land-cover discrimination especially in tropical rain forests. The most common data analysis techniques employed in these papers were regressions between bands and supervised classification procedures. The review indicated that land-cover mapping and direct estimation of land-cover parameters using AVHRR data is still at an early stage of development. Applications of AVHRR data for these purposes, however, are likely to increase with the availability of 1 km standard products.

2.41. Compiling a Digital Map of Areas Managed for Biodiversity in California

K. Beardsley
D.M. Stoms

Appears in: *Annual Summary Report for NASA Research Grant NAGW-1743*
February, 1994

To determine how well the biological diversity of a region is protected, one must know the locations of managed areas and the level of management being provided at each. In this paper we outline some of the difficult problems confronting cartographers in compiling a digital map of managed areas. These problems involve the classification of management levels, selection of minimum mapping unit, integration of maps from different sources, and the maintenance on data of rapidly changing land ownership. We demonstrate how these problems were resolved for a managed areas map for the state of California. Characteristics of an ideal geographic information system (GIS) database of managed areas are also described. The California map is being produced at a scale of 1:100,000 with a minimum mapping unit of 200 ha for uplands and 80 ha for wetlands.

Mapping has been completed for the Southwestern California Ecoregion, and the results and lessons learned are reported here. For this 3-million-ha study region, 9.8% of the total land area was classified at the highest level of protection; these managed areas are concentrated in higher elevation areas. Only 12.1 % of Significant Natural Areas in the region, as identified by the California Lands and Natural Areas Program, are currently within well-protected areas.

2.42. Modeling and Monitoring Regional Floristic Diversity Using Environmental Measures

K. McGwire
D. Fairbanks
K. Cayocca
J. Estes

Appears in: *Annual Summary Report for NASA Research Grant NAGW-1743*
February, 1994

The Remote Sensing Research Unit of the University of California is investigating relationships between environmental parameters and floristic composition and diversity at regional scales. Using the entire state of California as a test site, this regional ecological characterization uses GIS-based data on climate, soils, and topography to find whether predictable relationships exist between the species composition of natural vegetation communities and measurable environmental parameters. The goal of this research is to model long term changes in the character of natural vegetation given different scenarios of global climate change. Such information will be of value in species preservation efforts and may also enhance terrestrial modeling components in Earth Systems

Science. Modeling based on environmental data is complemented by remotely sensed monitoring of sensitive ecosystem boundaries. The ability of multi-scale imagery to characterize both ecotones and species turnover within communities is being examined.

2.43. Spatial Structure, Sampling Design and Scale in Remotely-Sensed Imagery of a California Savanna Woodland

K. McGwire
M. Friedl
J. E. Estes

Appears in: *International Journal of Remote Sensing, Volume 14, Number 11.*
February, 1994

This article describes research related to sampling techniques for establishing linear relations between land surface parameters and remotely-sensed data. Predictive relations are estimated between percentage tree cover in a savanna environment and a normalized difference vegetation index (NDVI) derived from the Thematic Mapper sensor. Spatial autocorrelation in original measurements and regression residuals is examined using semi-variogram analysis at several spatial resolutions. Sampling schemes are then tested to examine the effects of autocorrelation on predictive linear models in cases of small sample sizes. Regression models between image and ground data are affected by the spatial resolution of analysis. Reducing the influence of spatial autocorrelation by enforcing minimum distances between samples may also improve empirical models which relate ground parameters to satellite data.

2.44. A Comprehensive Managed Areas Spatial Database for the Conterminous United States: Procedures, Problems, and Relevant Issues Encountered in Compiling and Integrating Multiple Data Sources

G. McGhie
J.E. Estes
J. Scepan

Appears in: *Annual Summary Report for NASA Research Grant NAGW-1743*
July, 1996

This paper describes the compilation of a comprehensive, spatially referenced, digital database of managed areas in the conterminous United States. As concern over ecosystem degradation increases, so does the need for accurate, up-to-date information on the spatial location and aerial extent of currently managed and protected areas. This need represents the fundamental motivation for

creation of this Managed Areas Database (MAD). MAD includes information on the level of protection each management designation provides, sources used for compilation, and a number of additional attributes. MAD can be used with supplementary data sets for conservation planning, and to determine protection status. The authors believe that this database can and will support a wide variety of environmental studies. We believe, after appropriate verification and revision, that it may someday be part of a necessary global coverage of managed areas.

2.45. EOSDIS Potential User Model Document

J.E. Estes
K. Kline
J. Scepan

Appears in: *Annual Summary Report for NASA Research Grant NAGW-1743*
February, 1996

This report documents the conclusions of the Earth Observing System Data and Information System (EOSDIS) Potential Users Conference. The goal of this conference was to provide an authoritative statement of the needs and characteristics of the potential users of EOSDIS. EOSDIS provides, and will continue to provide, the basic means of accessing the data and information products of NASA's Mission to Planet Earth (MTPE), including the Earth Observing System (EOS). EOS is being implemented to acquire global data by sensor systems operating at wavelengths across the electromagnetic spectrum. EOSDIS is a distributed data and information system that is being implemented to help the user community acquire the data and information they require. NASA's MTPE, is a component of the U.S. Global Change Research Program, which was initiated to understand the interactive physical, biological and socioeconomic processes that regulate the total Earth system and to predict how this system will change in response to natural forces and human actions. Mission to Planet Earth includes EOS, a set of EOS precursor and Earth Probe satellite missions, NASA's Earth Science Research and Analysis Program, and EOSDIS. Thus, the products of MTPE will consist primarily of sets of satellite remote sensing data and the diverse information associated with them.

The community of current and potential users of environmental remote sensing data and research results is extensive and varied. To adequately represent this diversity, the potential user community was divided into twelve broad somewhat overlapping segments. These groupings were not intended to be exclusive, as it was realized that some users could function in more than one way. A chair and chapter writing committee were selected for each segment. Participants were selected by the chapter chairs in concert with the overall conference co-chairs. They constitute a representative set of authorities in the various areas covered. This report is a reasonable statement of the current view of the potential user community of EOSDIS. Chapter chairs together with the Potential User Model Development effort co-chairs constitute the overall editorial committee for this document. Work on this report began in December, 1994 and the conference was held during the week of June 19 - 22, 1995 near Leesburg, Virginia.

The twelve potential user groups represented in this effort are:

1. Retrospective Research
2. Field Campaigns and Individual Data Providers
3. Persistent Information Production for Research
4. Scientific Environmental Assessment
5. Commercial Users
6. Operational Users
7. Resource Planners and Managers
8. Policy Formation and Decision Making
9. The Legal Community
10. K-12 Education
11. Collegiate and Professional Education
12. Libraries, the Press, and the Public

2.46. Accuracy Analysis and Validation of Global 1 Km Land Cover Data Sets

J. Scepan
J.E. Estes
W.J. Starmer

Appears in: *Annual Summary Report for NASA Research Grant NAGW-1743*
February, 1996

In this study, an approach for analyzing and validating thematic and positional accuracy of high resolution global land cover data set is described. Portions of the International Geosphere - Biosphere Programme's (IGBP) 1 Kilometer Land Cover Data Set are used as a test bed to evaluate procedures for accuracy assessment and validation. The 1 Km Land Cover Data Set contains 17 land cover classes ranging from natural vegetation to developed land and non-vegetated classes.

This study focuses on developing statistical map accuracy procedures for data set validation through a continental scale cross validation exercise using the 1 KM land cover data set. The objective of this exercise is to assess the potential of the IGBP fast track validation procedures. These include implementation of an integrated overall map accuracy analysis as well as a detailed category specific thematic accuracy assessment for both a North American and African study site. Specific goals of this study are to:

- 1) determine whether different classification techniques employed for Africa and North America significantly affect the classification of the 1Km Land Cover data set;
- 2) determine whether systematic differences are introduced into the datasets by the separate processing flows;
- 3) examine and attempt to explain any non-systematic differences which may be identified, and;

- 4) derive a statistical estimate of these differences between the two datasets for each of the 17 Land Cover classes -- or as many of the classes as are adequately represented.

2.47. A Comprehensive Managed Areas Spatial Database for the Conterminous United States

R.G. McGhie
J. Scepan
J.E. Estes

Appears in: *Photogrammetric Engineering and Remote Sensing*. Volume 62, Number 11.
November, 1996

The compilation of a comprehensive, spatially referenced, digital database of managed areas in the conterminous United States is described. As concern over ecosystem degradation increases, so does the need for accurate, up-to-date information on the spatial location and aerial extent of currently managed and protected areas. This need represents the fundamental motivation for creation of this Managed Areas Database (MAD). MAD includes information on the level of protection each management designation provides, sources used for compilation, and a number of additional attributes. MAD can be used with supplementary data sets for conservation planning, and to determine protection status. The authors believe that this database can and will support a wide variety of environmental studies. We believe, after appropriate verification and revision, that it may someday be part of a necessary global coverage of managed areas.

2.48. Toward the Use of Remote Sensing and Other Data to Delineate Functional Types In Terrestrial and Aquatic Systems

J.E. Estes
T.R. Loveland

Appears in: *Approaches To Scaling A Trace Gas Fluxes In Ecosystems* A.F. Bouwman, editor. 1999 Elsevier Science B.V.
August, 1999

Spatially accurate thematic data, such as land cover, are required for studies addressing a broad range of issues. These issues, which span local to global scales, include biodiversity, desertification, deforestation, freshwater supply and quality, demography, and poverty. Spatial data are also important for investigations of ecosystems health, air quality, and all the issues being addressed by the international science community engaged in global change research. Availability of required data is, however, an important factor hindering both fundamental and applied research on these and other issues. It is generally true that adequate land cover maps, as well as other types of

thematic data, do not exist for many areas of the world. This statement is equally true, depending upon scale, thematic content, and timeliness, for both the developed and developing nations.

For some time, it has been recognized that there is considerable ignorance concerning the global distribution of vegetation types. This lack of knowledge of the distribution and dynamics of our global vegetation cover types is an issue of increasing concern given the rate of transformation of the Earth's vegetation cover, and the profound impacts that these changes are having on our global environment and the sustainability of economic development. Changes in land surface cover associated with agriculture, human settlements, and other purposes are among the most pervasive and obvious impacts of human activities on the global environment. Local land cover changes can and do have profound implications for the functioning of local to global scale ecosystems, biogeochemical fluxes, and climate. Despite the widespread recognition that mankind's intimate involvement in these fundamental transformations of the surface of the Earth have profound and lasting impacts, there is no reliable, comprehensive global data base of land cover changes.

Increasing attention is being given to the issue of establishing comprehensive, coordinated, operational science quality global measurement, mapping, monitoring, and modeling programs. However, to our knowledge, no such programs exist. Today, no civil organization that we are aware of has a global mapping charter; no civil agency globally has the resources, or the backing of its respective government, to aggressively develop a major, high resolution, science based global scale mapping effort. Additionally:

- 1) Large scale, science-based data sets do not exist for most of the Earth at the present time, even in highly developed countries;
- 2) Development of such data sets is labor intensive, in terms of both scientific and technical personnel, and is, therefore, labor expensive;
- 3) Although such data sets could support a wide variety of useful applications specific to a given locale, no single use can generally justify the cost of their development;
- 4) In many developing countries, even well understood environmental changes with local causes and effects that, in the aggregate, may represent a global concern, often have very low priority with officials compared to such issues as food, health care, and safety of the people. Global change issues and environmental concerns are often treated as rumors from more fortunate neighbors;
- 5) In a number of countries, the high-resolution data sets needs by the world community are classified and are not permitted to leave the country in any form. In some instances where such data are exchanged with "friendly" nations, restrictive agreements limit access to these data; and
- 6) Even in highly developed countries, where scientific understanding is widespread, it is often difficult to generate the political and financial support for the correction of widely recognized environmental problems.

While the lack of comprehensive and coordinated programs is a major hindrance to long term science and sustainable development initiatives, there are three encouraging movements underway that may improve this situation. First, the commitment to space-based remote sensing by many nations is leading to an unprecedented era of new, multi-resolution remotely sensed data sets. Second, there are a few project-level activities underway to develop some of the required spatial thematic data sets. These projects, largely funded by global change research programs, are typically

one-time efforts. Third, there is now organized dialog among representatives of national mapping agencies concerning the development of global map data. While these movements do not provide immediate solutions, they are all signs we are moving in the right direction. In spite of these positive steps, these facts remain:

- We know little about the distribution of global vegetation types;
- We have no well coordinated, operational, globally distributed measurements of key parameters associated with the determination of trace gas fluxes between terrestrial and aquatic ecosystems and the atmosphere;
- No programs for operationally monitoring changes in patterns of surface cover exists at scales above local; and
- Without such programs, the modeling of global trace gas fluxes has inherent flaws.

This paper will primarily focus on the role that remotely sensed data play in improving our ability to document the distribution of global land cover types. Given that the relationships between these cover types and trace gas fluxes can be unambiguously established, then the dynamics of these fluxes can be established. Brief attention will also be given to important aquatic systems, such as wetlands, and the land/water interface. A detailed discussion of functional aquatic types, including oceans, limnological, riverine, and other aquatic systems, is beyond the scope of this paper.

The remainder of the paper addresses four points. First, a discussion of the role of land cover data in environmental assessments, and those issues important in the analysis of trace gas fluxes is given. Second, a general background on the interpretation of remotely sensed data is provided, and key issues in the use of such analyses to create map products are addressed. This discussion covers some of the misconceptions within the scientific community concerning the use of remotely sensed data for the creation of surface cover products. Third, the information factors important to consider in the creation of cover type maps are identified. Here we focus on issues such as: strategies for such mapping, legend development, large area mapping from remotely sensing data and accuracy assessment. Finally, we offer conclusion and some recommendations directed specifically at the creation of future thematic products from remotely sensed data for scaling trace gas fluxes between terrestrial and aquatic systems and the atmosphere.

2.49. A Reference Framework for Global Environmental Data

K.E. Anderson
K. Kline

Appears in: *The Challenge of Global Data - New Directions for Global Environmental Databases. ISPRS Commission VI, Chapter*
September, 2000

From the beginnings of time, man has been creating images of his world, 'maps', to understand the relative location of cities or important resources such as water and gold. Over 2000 years ago there

were 'global' maps to support international trade. Examples of these include Polynesian sailing charts made from shells and sticks. Now, we are in an era that needs new and better maps of our world to manage and protect our resources, ensure our safety and health, and promote business and growth. While ever more satellites are launched into orbit around the earth, providing a variety of sensors to examine our world, the raw data collected must be processed, analyzed, and organized into forms that will support the ongoing scientific studies.

Resolutions and recommendations related to the Global Mapping Concept have been repeatedly adopted at many international conferences since as early as the end of the nineteenth century. The development of remote sensing and geographic information systems and related geospatial technologies in the latter years of the twentieth century has made the development of maps of this kind more realistic and feasible than ever before.

2.50. The International Steering Committee for Global Mapping: Current Status and Future Plans and Challenges

J.E. Estes
K.D. Kline

Appears in: *Annual Summary Report for NASA Research Grant NAG5-3620*
September, 2000

Many people cannot believe that accurate, up to date, global scale map data do not exist. They believe that such products are already widely available. That the products they do see are accurate, up to date, and are inexpensive and simple to make. This is so even though we, attending this conference, know that none of the above are true. We collectively do not effectively communicate to policy decision makers at appropriate levels the problems with the maps that do exist. That producing high quality map products in a timely fashion is an expensive process. That as technology has advanced, the fundamental science underpinning mapping must advance as well.

We have not "spread the word" that among other things, the lack of accurate, up to date, global geospatial data in map form should be of concern at many levels. Without such data, compliance with international accords is difficult to assess. Without such data, relief efforts, in cases of natural disasters, can be impacted. Without such data, planning required for economic development and/or for the preservation of diversity can be affected.

The paper that follows discusses the Global Map project of the international Steering Committee for Global Mapping (ISCGM). In addition to conducting this project, ISCGM members are working to educate people on the importance and difficulties associated with the creation of global map products. The paper that follows describes the current status of the project, plans for the future, and challenges we face as we attempt to further develop global map products and to create more informed consumers and funding agencies.

2.51. The IGBP-DIS Global 1-Km Land-Cover Data Set DISCover: A Project Overview

A.S. Belward
J.E. Estes
K.D. Kline

Appears in: *Photogrammetric Engineering & Remote Sensing Vol. 65, No. 9*
September 1999

Since 1992 the International Geosphere Biosphere Programme's (IGBP) Data and Information System (DIS) has been working towards the completion of a validated global landcover data set, DISCover. This 1-km resolution data set consists of 17 cover classes identified on the basis of the science requirements of the IGBP's core projects. DISCover has been created from over 4.4 Terabytes of data from the Advanced Very High Resolution Radiometer collected from 23 receiving stations. These data were processed and assembled into a coherent set of monthly Normalized Difference Vegetation Index composites (April 1992 to April 1993) and classified using unsupervised techniques with post-classification refinement. The first global land-cover classification was completed in July 1997. The IGBP-DIS Land Cover Working Group, in turn, convened a Validation Working Group to provide and implement a validation method to provide statistical statements concerning the accuracy of the global land-cover product and to allow the estimation of the error variance in area] totals of classes globally and within regions. The validation workshop was completed in September 1998 and the analysis by March 1999. This paper describes the history of the DISCover version 1.0 implementation.

2.52. Landsat Thematic Mapper Registration Accuracy and its Effects on the IGBP Validation

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K.C. McGwire

Appears in: *Photogrammetric Engineering & Remote Sensing Vol. 65, No. 9*
September 1999

Research associated with the International Geosphere/ Biosphere Programme Data and Information System Cover (DISCover) validation exercise revealed possible registration errors in the high-resolution data employed. Systematically corrected National Landsat Archive Production Systems (NLAPS) Thematic Mapper (TM) data used in the validation of the DISCover dataset was compared with precision registered Multi-Resolution Land Characteristics (MRLC) TNI data available only for the conterminous United States. A consistent offset in the systematically corrected data was discovered to be approximately 1 km to the east and south. The impacts of this bias on the validation of the IGBP Discover dataset are examined and show that possibly 20 percent of the IGBP pixels for the conterminous United States could be adversely affected by this registration

error. Fractal dimension is shown to have a close relationship with the effect of the offset on a class, and may be used as a predictive tool for areas outside the conterminous United States.

2.53. Image Interpretation Keys for Validation of Global Land-Cover Data Sets

M. Kelly
J.E. Estes
K.A. Knight

Appears in: *Photogrammetric Engineering & Remote Sensing Vol. 65, No. 9*
September 1999

Photointerpretation keys originated from the need to efficiently train aerial photographic interpreters. Keys provide interpreters with a baseline of signature information that can be widely applied to images illustrating differing land covers, features, facilities, processes, and activities. Keys were produced for the International Geosphere Biosphere Programme Data Information Systems (IGBP-DIS) DISCover Validation effort. This effort had two objectives: to provide a prototype set of image interpretation keys that could be produced efficiently and cost effectively, and to create a foundation of enduring reference materials that could be refined and enlarged to facilitate the validation of future global land-cover products. The methodology of key development and production for this effort originated as an ideal, but has by necessity been shaped by pragmatic considerations. Factors including cost, time, and availability of imagery and ancillary data limited broad applicability of the keys developed. Research included determination of the most effective band combination, signature development and application, consistent implementation of a minimum mapping unit, use of signature elements in the evaluation of key use, and development of a product useful for cross applications. We continue to expand the present set of keys and develop a digital infrastructure for a global reference library of key materials. These materials will expedite future validation efforts and lead to greater confidence in the accuracy of future global land-cover products.

2.54. Thematic Validation of High-Resolution Global Land-Cover Data Sets

J. Scepan

Appears in: *Photogrammetric Engineering & Remote Sensing Vol. 65, No. 9*
September 1999

This paper describes a procedure to validate the thematic accuracy of the International Geosphere-Biosphere Programme, Data and Information System (IGBP-DIS) Discover (Version 1.0) 1-Kilometer Global Land-Cover Data Set. Issues of data set sampling design, image geometry and registration, and core sample interpretation procedures are addressed. Landsat Thematic Mapper and SPOT satellite image data were used to verify 379 primary core samples selected from

Discover 1.0 using a stratified random sampling procedure. The goal was to verify a minimum of 25 samples per Discover class; this was accomplished for 13 of the 15 verified classes. Three regional Expert Image Interpreters independently verified each sample, and a majority decision rule was used to determine sample accuracy. For the 15 Discover classes validated, the average class accuracy was 59.4 percent with accuracies for the 15 verified Discover classes ranging between 40.0 percent and 100 percent. The overall area-weighted accuracy of the data set was determined to be 66.9 percent. When only samples which had a majority interpretation for errors as well as for correct classification were considered, the average class accuracy of the data set was calculated to be 73.5 percent.

2.55. The DISCover Validation Image Interpretation Process

J. Scepan,
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M.C. Hansen

Appears in: *Photogrammetric Engineering & Remote Sensing Vol. 65, No. 9.*
September 1999

Thematic validation of the International Geosphere Biosphere Data and Information System (IGBP-DIS) Global 1-Kilometer Land-Cover Data Set (Discover) was performed utilizing a "state-of-the-practice" technique by a team of Expert Image Interpreters (EII) examining subscenes extracted from 379 digital Landsat TM (Thematic Mapper) and SPOT images.

The 15 validated IGBP land-cover classes (Snow/Ice and Water were not assessed) were not equally interpretable on the TM and SPOT imagery. Interpreter confidence was highest for Evergreen Broadleaf Forests and Urban/Built-up Discover classes while Grasslands and Permanent Wetlands were interpreted with relatively less confidence. Analysis of image interpretation in each of the 13 validation regions indicates that confidence in interpretations for North America/Canada (Region 1) and Central Asia/Japan (Region 11) are lower than average. Confidence in interpretations is significantly higher than average for North America/US (Region 2), Northern and Southern South America (Regions 4 and 5), and Southeast Asia and China (Region 12). In this study, variations in interpretation confidence are also noted between regions or based upon the geographic location of samples.

This exercise demonstrates that Landsat TM and SPOT imagery can be efficiently used to validate high-resolution global land-cover products. The results suggest that the utility of and confidence that may be placed in this technique depends upon the land-cover classification scheme used and the quality of digital and ancillary data available to aid interpreters. Another important factor is the relative confidence of the interpreters to verify the land cover within their respective areas of the globe.

2.56. The Way Forward

J.E. Estes
A. Belward
T. Loveland
J. Scepan
A. Strahler
J. Townshend
C. Justice

Appears in: *Photogrammetric Engineering & Remote Sensing Vol. 65, No. 9.*
September 1999

This paper focuses on the lessons learned in the conduct of the International Geosphere Biosphere Program's Data and Information System (IGBP-DIS), global 1-km Land-Cover Mapping Project (Discover). There is still considerable fundamental research to be conducted dealing with the development and validation of thematic geospatial products derived from a combination of remotely sensed and ancillary data. Issues include database and data product development, classification legend definitions, processing and analysis techniques, and sampling strategies. A significant infrastructure is required to support an effort such as Discover. The infrastructure put in place under the auspices of the IGBP-DIS serves as a model, and must be put in place to enable replication and development of projects such as Discover.

2.57. Textbook improvements for Introductory GIS Classes

K.C. Clarke

“Getting Started With Geographic Information Systems”, Fourth Edition.
2003 (in press)

The introductory GIS textbook, “Getting Started With Geographic Information Systems” is widely used in colleges and universities worldwide. In this recent time period improvements were made to the Fourth Edition to include the new changes in Remote Sensing Platforms, and a new chapter on mapping New York City after the September 11th terrorist attacks. One key component in the mapping efforts is the incorporation of remotely sensed imagery with the property maps in use by the City of New York.

2.58. Model comparison using interpolation versus Aerial Photography-derived urban modeling

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Re-creation of the extent of urban land use at different periods in time is valuable for examining how cities grow and how policy changes influence urban dynamics. To date, there has been little focus on the modeling of historical urban extent (other than for ancient cities). Instead, current modeling research has emphasized simulating the cities of the future. Predictive models can provide insights into urban growth processes and are valuable for land-use and urban planners, yet historical trends are largely ignored. This is unfortunate since historical data exist for urban areas and can be used to quantitatively test dynamic models and theory. We maintain that understanding the growth dynamics of a region's past allows more intelligent forecasts of its future. We compare using a spatio-temporal interpolation method with an agent-based simulation approach to recreate the urban extent of Santa Barbara, California annually from 1929 to 2001. The first method uses current, yet incomplete data on the construction of homes in the region. The latter uses a Cellular Automata (CA) based model, SLEUTH, to back- or hind-cast the urban extent. The data for SLEUTH was derived from historical panchromatic aerial photography.

The success at historical urban growth reproduction of the two approaches used in this work was quantified for comparison. The performance of each method is described, as well as the utility of each model in re-creating the history of Santa Barbara. Additionally, the models' assumptions about space are contrasted. As a consequence, we propose that both approaches are useful in historical urban simulations, yet the CA approach is more flexible as it can be extended for spatio-temporal extrapolation. One necessity for the SLEUTH approach is obtaining good historical data as provided from aerial photography.

3. Current Research Activities

3.1 Applied Research Activities

3.1.1. NASA ESA Research Grant Performance Metrics Reporting

Initially created by RSRU Postgraduate Researcher M.J. Lawless as a method of determining the scope and nature of NASA funded research, as well as providing quantitative data on the performance of NASA funded research programs, the NASA Research Grant Performance Metrics Project (NRGPMP) was reinstated and updated in 2002.

This material is currently located at:

<http://rsruweb.geog.ucsb.edu/metrics2002.asp>

This interactive reporting form was created to provide a direct link between researchers and a database containing information about the nature and costs of their research project. This information in turn can be communicated easily, either in whole or part, to NASA personnel. Information collected from grant recipients includes the nature and cost of the research, the outcome of the project, and any significant contributions to public knowledge (publications, patents, created new technologies, TV appearances, etc). For a complete list of metrics collected from users please see above web link.

The website is run through the University of California, at Santa Barbara's Geography Department web site. Located on a Windows based PC, the site entire site consists of a website using an extensive form data entry page created using Microsoft Frontpage. After researchers fill in the metrics form, the information is automatically transferred to a Microsoft Access database. Updated in this past year, the newest version of this database has been designed to run with little or no maintenance for several years. The form was completely recreated from the original design, and set up to merge seamlessly with the database from the previous effort by Lawless. Additionally, several safeguards were installed in the system to minimize unwanted access.

3.2. Information Science Research

3.2.1. Global Data Set Thematic Accuracy Analysis

In a broad international effort, the thematic accuracy of the IGBP Global 1-km Land Cover Data Set (v.1.0 IGBP-DIScover) was statistically assessed. This work was documented previously in the final technical report for NASA Research Grant NAG5-3820. Accuracy of the DISCover 1.0 product was assessed by a core sample of approximately 379 primary (or "core") samples in a procedure that yields confidence limits on the accuracy of classification as well as on specific probabilities of misclassification. In addition, the core sample were expanded into "confidence sites": larger regions around each sample center that were used for fine resolution land cover mapping as specified in the IGBP-DIS protocol.

This research directly addressed the primary I.CLUC goal of developing the capability to perform global inventories of land cover and land use from space, a process in which accuracy assessment is a critical part. It also directly addressed the call for development of techniques and methods for applying satellite data to land use and land cover problems.

During the past year, additional research aimed at topics related to the validation effort has been initiated in RSRU. This research has generally concentrated on the role that the individual Expert Image Interpreters played in the validation process. Specific focus has been on three issues:

1. analysis of thematic sample assignment variability among interpreters;
2. the effects of different image spectral band combinations in sample verification; and,
3. the impacts of thematic and spatial variability in interpretation confidence.

3.2.2. ISCGM/Global Map project support

From 1995 until his death in March 2001, Professor Estes was involved with the Global Map Project as the Chair of the International Steering Committee for Global Mapping (ISCGM). This organization is leading the effort to produce the Global Map, a globally consistent data set comprised of data contributed by national mapping agencies from around the world. The ISCGM is made up primarily of individuals who either are, or directly represent, the heads of National Mapping Agencies. The ISCGM Secretariat is housed in the Geographical Survey Institute of the Ministry of Construction, Japan, Japan's National Mapping Agency. Individuals from other interested organizations or agencies, who want to advance the cause of global mapping development, can participate as either advisors or observers. In addition, National Mapping Agency's (NMAs) are not required to be members of the ISCGM to participate in the Global Map Project. At present there are some 17 ISCGM members, 7 Advisors, and 21 countries represented by Observers. The number of observers varies from meeting to meeting due to the ability of potential participants to attend the meeting. As seen in Figure 1, participation in the Global Map Project has reached more than 75 nations, with more countries anticipated to join in during the next year (Secretariat of International Steering Committee for Global Mapping 1996; Secretariat of International Steering Committee for Global Mapping 1996; Secretariat of International Steering Committee for Global Mapping 1997; Secretariat of International Steering Committee for Global Mapping 1998; Secretariat of International Steering Committee for Global Mapping 1998; Secretariat of International Steering Committee for Global Mapping 1999; Secretariat of International Steering Committee for Global Mapping 2000; Secretariat of International Steering Committee for Global Mapping 2001).

Figure 1 below depicts those countries that are participating in the Global Map project. The color code is as follows:

- Red = Level A participation, these countries will provide the data of their national territory AND assist a Level C country
- Green = Level B participation, these countries will provide the data of their national territory

- Blue = Level C participation, these countries will work with a Level A country to produce their data
- Yellow = ESRI Grant Participant, these countries will receive a grant from the Environmental Systems Research Institute and will be required to participate (more information below)
- Gray = These countries have indicated they are interested and plan on participating, but have not determined at which level yet

Level of Participation in ISCGM Global Map Project

As of 12 September 2002

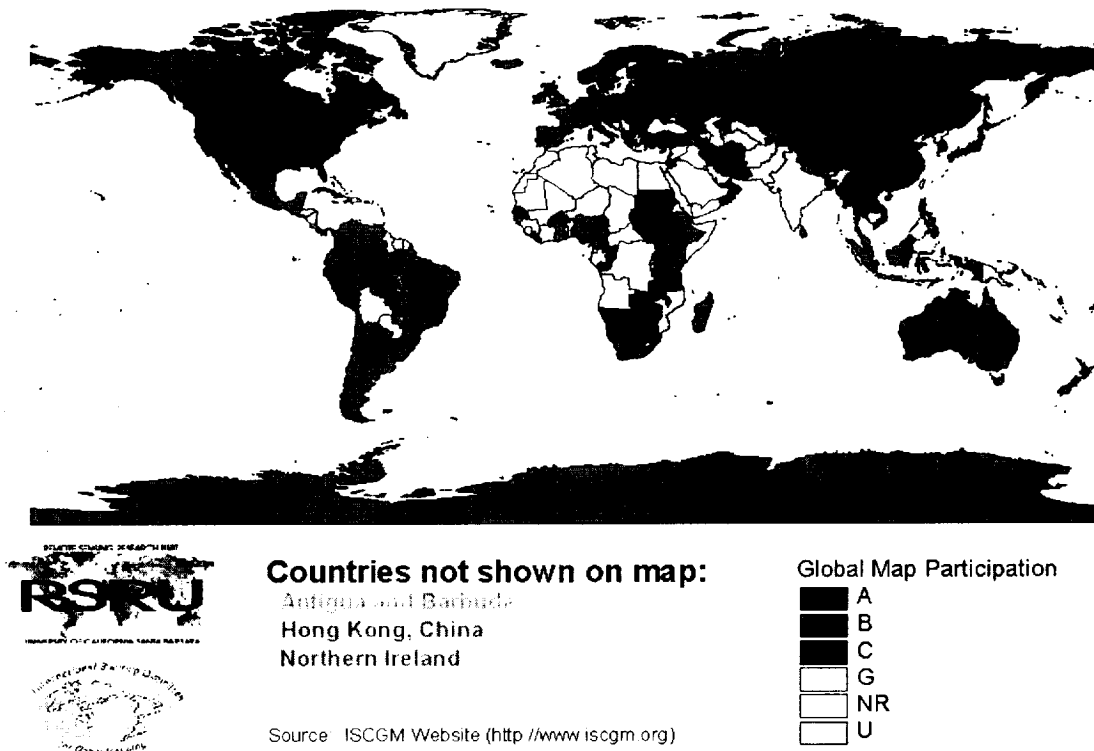


Figure 1 Participation in the Global Map Project

In addition to providing a forum for the exchange of information among NMAs, ISCGM is coordinating the upgrading of small-scale globally consistent data sets. ISCGM's goals are to promote cooperation and collaboration among NMAs for the development and dissemination of improved products that can support a variety of users from public policy decision makers to resource planners and environmental managers. Professor Estes and ISRG/RSRU personnel have worked with ISCGM members and the Secretariat on an action plan and specifications for the global map product, and the determination of the current status of global map coverage.

As defined by ISCGM, a “global map” is a data set consisting of several core data layers and meets the following requirements:

1. Covers the entire surface of the earth;
2. Meets consistent specifications for the entire planet;
3. Many people can access these data; and
4. Must be updated regularly.

The core data layers of the Global Map version 1.0 product are: administrative boundaries, land use, vegetation, drainage systems, elevation, and transportation networks (see Figure 2). The base data product will consist of data from various pre-existing global data sets, identified and described below.

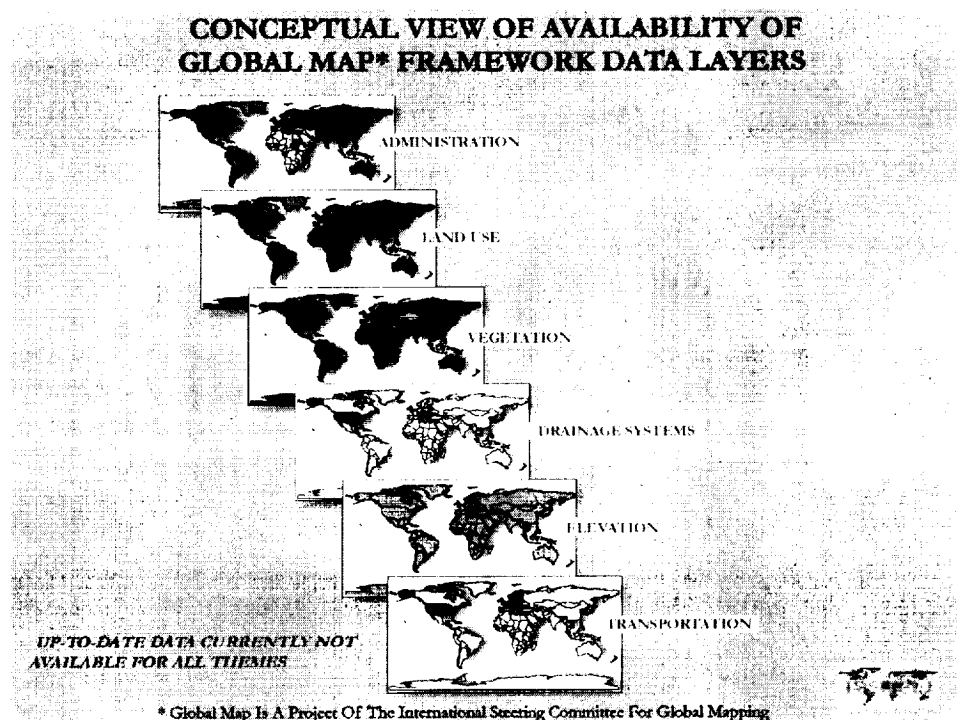


Figure 2 Global Map Framework Data Layers

Vector Map Level 0 was formerly the Digital Chart of the World, and is produced by the U.S. National Imagery and Mapping Agency. It is a global database that includes roads, railroads, rivers, lakes, streams, major utility networks, cross-country pipelines, communication lines, airports, elevation, coastlines, international boundaries, populated places, and geographic names. The data are from the Operational Navigation Charts and the Jet Navigation Charts. This product is available for \$200.00 US. VMap0 will provide the administrative boundaries, drainage systems, and transportation network layers.

GTOPO30 is a global 30 arc second digital elevation data set. It is produced by the USGS' EROS Data Center and is available from EDC either over the Internet, CD-ROM, or 8 mm tape. The data

are from the Digital Chart of the World and other previously existing elevation data. GTOPO30 will be the elevation data layer of Global Map (Verdin and Jenson 1996).

The IGBP DISCover land cover characteristics database was derived from a yearlong series of AVHRR NDVI composites. There are 17 different land cover classes in the IGBP legend. This data is available from the EROS Data Center web site. The land cover (vegetation) layer will come from the IGBP DISCover data set (Loveland and Belward 1997; Belward, Estes et al. 1999).

These globally consistent thematic data sets are important for a variety of reasons. First of all, sustainable development researchers have a need for global data sets that adhere to “global map” specifications. Consistent and accurate data sets will have far reaching benefits for the sustainable development research community, as well as others. By having a regularly updated database containing a number of important layers or themes, it will be easier to track changes on the earth’s surface, and to determine whether or not development is sustainable. The global modeling community will also benefit from having a globally consistent database. This will allow them to model various regions of the earth's surface and make comparisons between regions, as well as to create global models. By making the data widely accessible and easily available to everyone everywhere, environmental resource managers and planners can quickly and more accurately keep track of the resources for which they are responsible.

With these goals in mind, the activities of the ISCGM have continued to the present, with plans for many future activities. Regular meetings of the Steering Committee have been held, many in conjunction with other meetings. These include the 8th and 9th meetings, held in Cartagena, Colombia and Budapest, Hungary, respectively. Important actions reported on at these meetings include (Secretariat of International Steering Committee for Global Mapping 2001):

- The announcement by Mr. Jack Dangermond of Environmental Systems Research Institute (ESRI) of the formation of the Estes Global Map/GSDI grant;
- The nomination and acceptance of Dr. Fraser Taylor, Carleton University, Ottawa, Ontario, Canada, as the new Chair of the ISCGM;
- The nomination and acceptance of Ms. Karen Kline of RSRU/UCSB as the Assistant Secretary General of the Secretariat for the ISCGM; and
- Version 2.0 planning underway, discussions have covered such topics as additional layers and validation methodology.

Since the Global Mapping Forum 2000 in Hiroshima, Japan, where the release of Global Map Version 1.0 was announced, several other countries have since processed their data and contributed it to the Secretariat of the ISCGM for release. Once the data have been submitted, they are then tested by the Secretariat to ensure that it meets the specifications and standards determined by the ISCGM. The data are then placed upon the ISCGM website where they may be downloaded. Figure 3 below shows those countries, which have completed their contribution, and others who have communicated the status of their data to the Secretariat.

Status of Global Map Data As of 12 September 2002

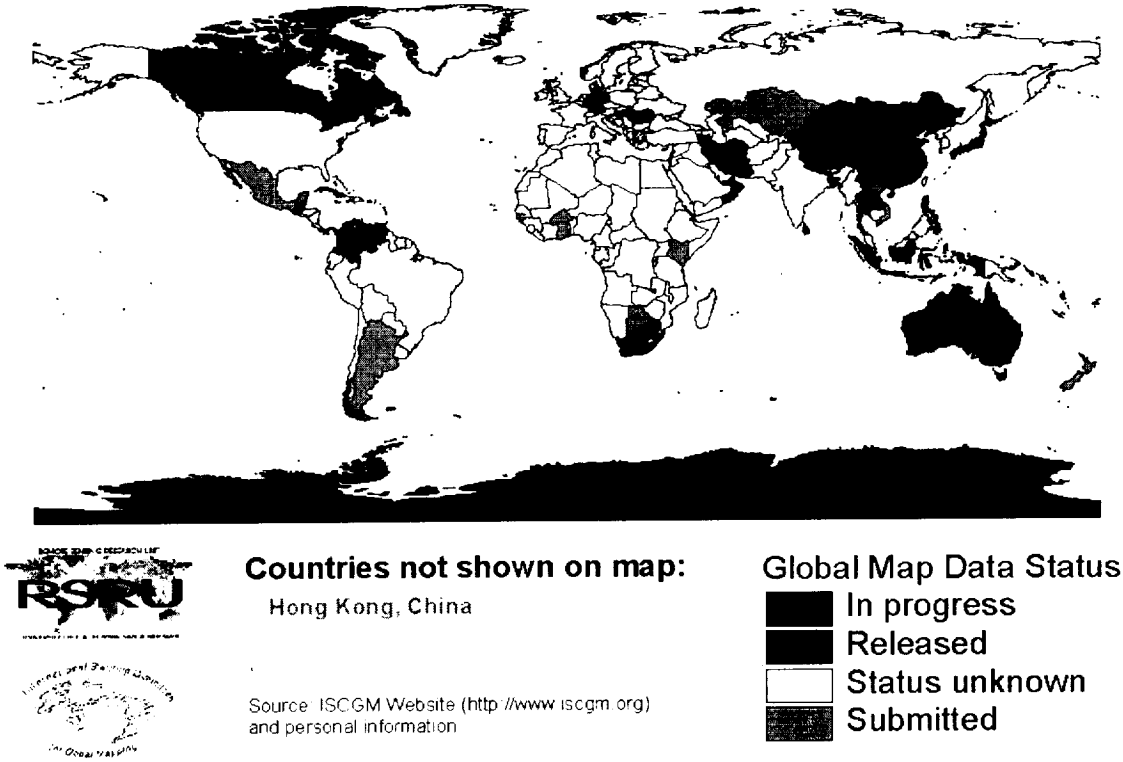


Figure 3 Global Map Data Status (Released and in Progress)

RSRU personnel have been actively involved with ESRI and GSDI representatives in reviewing the applications for the ESRI grant and determining the appropriate organizations to receive the awards. In addition, presentations have been made at the two training sessions that have been organized (July and September 2002).

While it is important to note the success of an organization such as this in bringing together many different participants from around the world, and bringing together their data, this work will be continuing indefinitely.

3.2.3. Cooperative International Activities

Throughout the approximately twenty-five year history of the Remote Sensing Research Unit, cooperative international activities have played a large role. ISRG/RSRU researchers have been involved in a variety of cooperative activities in the international arena. These have included work with agencies such as:

- United Nations Development Program (UNDP);
- United Nations Environment Program (UNEP);
- United Nations Institute for Training and Research (UNITAR);

- United Nations Educational Scientific and Cultural Organization (UNESCO);
- World Conservation Monitoring Center (WCMC);
- International Steering Committee for Global Mapping (ISCGM);
- Global Spatial Data Infrastructure (GSDI);
- International Society for Photogrammetry and Remote Sensing (ISPRS); and,
- Center for International Earth Science Information Network (CIESIN).

What follows is a summary of the most recent cooperative international activities focused on the International Steering Committee for Global Mapping (ISCGM), the Global Spatial Data Infrastructure (GSDI), and the Center for International Earth Science Information Network (CIESIN).

3.2.3.1. User Model Study of Global Environmental Data Sets

Global scale datasets have a long and varied history, going as far back as the late 1800s when Albrecht Penck first proposed the International Map of the World (IMW) at the Fifth International Geographical Congress (Department of Economic and Social Affairs 1975; Martin and James 1993; Winchester 1995). The IMW project had a tumultuous life, including two world wars, and was eventually officially terminated in 1986 by the United Nations. At that time, the IMW was the only effort that relied on data (or map) contributions from different countries to create the final product. The Global Map project has reactivated this methodology, and with the support of the technology available today, stands a much better chance of succeeding where the IMW failed. Much of the recent Global Map activity was initially spurred by the call for data from UNCED, the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992 to promote the importance of sustainable development (United Nations 1992). Agenda 21, the document resulting from this meeting, in Chapter 40, calls for new data to augment previously existing data:

40.2 While considerable data already exist, as the various sectoral chapters of Agenda 21 indicate, more and different types of data need to be collected, at the local, provincial, national and international levels, indicating the status and trends of the planet's ecosystem, natural resources, pollution and socio-economic variables. The gap in the availability, quality, coherence, standardization and accessibility of data between the developed and the developing world has been increasing, seriously impairing the capacities of countries to make informed decisions concerning environment and development (United Nations 1992).

After UNCED, the Geographical Survey Institute of Japan, as a response specifically to Chapter 40, "Information for decision-making," of Agenda 21 (United Nations 1992), began forming the idea of the Global Map Project, which officially began with the first meeting of the International Steering Committee for Global Mapping (ISCGM) in 1996 (Secretariat of International Steering Committee for Global Mapping 1996). Since that first meeting, Versions 0 and 1.0 of Global Map have been released, over 90 countries have participated in the project, and plans for updating Version 1.0 have begun.

The original Global Map Version 0 consists of transportation networks, populated places, political boundaries, elevation, land cover, land use, and vegetation. The transportation networks, population centers, and political boundaries were from the Vector Map Level 0 dataset created by the U.S. National Imagery and Mapping Agency (NIMA). The elevation data were from the GTOPO30

dataset created by the U.S. Geological Survey (USGS) with cooperation from the U.S. National Aeronautics and Space Administration (NASA), the United Nations Environment Programme/Global Resource Information Database (UNEP/GRID), the U.S. Agency for International Development (USAID), the Instituto Nacional de Estadística Geográfica e Informática (INEGI) of Mexico, the Geographical Survey Institute (GSI) of Japan, the Scientific Committee on Antarctic Research (SCAR), and the New Zealand Manaaki Whenua Landcare Research Ltd. (USGS EROS Data Center, 1999). The IGBP DISCover land cover dataset is the source for the land cover layer within Global Map. The vegetation and land use layers were derived from classification systems applied to the Global Land Cover Characteristics (GLCC) dataset compiled from monthly AVHRR NDVI composites. These data (Version 0 of Global Map) were then distributed to the participating countries for them to update and/or replace with data provided by their respective national mapping agencies.

The Global Map Version 1.0 consists of data contributed or updated by each of the participating countries and includes transportation networks, political boundaries, drainage networks, population centers, elevation, vegetation, land cover, and land use. The main difference between Version 0 and Version 1.0 is that the data contributed by the countries are either updated versions of the original data sent to the national mapping agencies or national level data sets created and maintained by the respective countries and submitted to the Global Map project. These data are available over the Internet from the Secretariat for the International Steering Committee for Global Mapping housed within the Geographical Survey Institute of Japan.

As the ten-year anniversary of the original UNCED meeting is soon to be reached and a new meeting (the World Summit on Sustainable Development (WSSD)) is now being planned for August and September 2002, it is important to determine whether or not the call for additional data, including global scale datasets, in Agenda 21 has been effective. As part of the review and analysis process in determining whether or not Agenda 21 has made any impacts, an analysis of whether or not there has been an increase in data available and whether or not these data are serving the needs of the users becomes quite relevant. Fundamental questions are: Who is using the global scale data sets? What are their data needs at the global level? Are these needs being met?

Particularly relevant to this analysis is the information collected from users downloading data from various data provider websites. Typically, data providers ask users to fill out a brief questionnaire, which often includes the following basic questions: The user's location, the user's affiliation, and the application for which the data will be applied. Additional information of interest, which most likely can be inferred from the information provided or from the data provider itself, include: The data source location (where were the data downloaded from), the user's application area (the study area), and the scale of interest (i.e., global, continental, regional, national, state, or local).

The specific hypotheses that are tested are:

- The location of the user affects the type of data used, the domain of the user, the application, the location of the research, and the level (scale) of interest.
- The domain of the user affects the type of data used, the application, the location of the user, the location of the research, and the level (scale) of interest.

- The application affects the type of data used, the location of the user, the domain of the user, the location of the research, and the level (scale) of interest.

Therefore, the work to be completed in this project includes the collection of user data from the United Nations Environment Programme (UNEP) Global Resource Information Database (GRID) sites, particularly Geneva and Arendal; the Global Map project user information from the Secretariat of the ISCGM; and the U.S. Geological Survey's EROS Data Center (EDC) GLCC data. The EDC data set was chosen because it was included in Global Map Version 0. The different UNEP/GRID sites were chosen because they are each located in different countries and serve more localized types of data in addition to global and regional scale data. It is expected that the data users can be placed into categories based upon their affiliation, such as academic, government, and industry. In addition, uses can also be categorized according to application, with the categories to be used based upon those used in both Lawless and Hadley's works on remote sensing applications (Lawless, 1996; Hadley, Estes et al., 2000; Hadley, 2001). These categories are: agriculture; air quality; economic development and conservation; emergency management; fisheries; forestry; geology; information and intelligence; land use and land cover; mapping, charting, and geodesy; marine; media, press, and education; public health; rangeland; recreation and tourism; transportation; urban and regional planning; water quality; water resources; and weather and climate. Additional categories can be added if necessary to cover any uses for which data providers are unaware.

Once the data have been categorized, comparisons between the types of users, the applications the data are used for, and the locations of the users will be made. The main hypothesis to be tested is that users tend to be interested in data covering their location. One area of particular interest is how the user's space (where the user is physically located) compares with their application space (the area of the earth's surface the downloaded data covers) with the provider's space (the location of the data server). What are the relationships between these three spaces? One of the key issues that must be kept in mind during this analysis includes the uncertainty of data collected over the internet. There is no system for validating the information users input before being allowed to download the data, other than not allowing blank fields. This factor will introduce a certain amount of uncertainty to the results.

Another question of interest is whether or not potential users must register before or after locating the data they are interesting in using. If it is before they can search, then a mechanism can be put in place to determine whether or not what they are looking for is available, which can assist a data provider in determining what data markets they are missing. If users register after locating data but before downloading, it is more difficult to determine whether they have identified this data set as exactly meeting their needs.

Besides the uncertainty introduced by the use of the Internet as a data provider, there are several other issues that must also be kept in mind during this analysis. The results of the analysis may also be conditioned by what data are available at each site -- do United Nations sites only serve United Nations derived and created data and provide it to mostly United Nations employees? Or do sites carry data created by a variety of data providers? Is a site in Europe (i.e., GRID Arendal) restricted to providing data covering Europe only? How can a data provider assess their site to determine whether or not they are providing the appropriate data for their users? Or is their site the only one providing this type of data, and hence becomes the default because there is no other provider? What types of data are served from different types of sites, i.e., government (USGS EDC) versus

non-government (ISCGM) versus UN? What types of discovery tools exist for locating data? And how do distribution and data policies differ among the different types of sites?

In summary, the work proposed here includes the collection of information about the users of global scale datasets from USGS EDC, ISCGM, and UNEP/GRID. This information will be synthesized and analyzed looking for patterns in the user's space, the application space, and the provider's space. It is hoped that this work will assist in evaluating the current status of global scale data, particularly with the upcoming review of progress since 1992's UNCED meeting.

Literature Review

Global map creation activities have had a long history. Murakami (1993) divided modern "global geographic dataset production" into two phases: 1891 to 1960 and 1960 to the present. Estes (2001 (UNRCC Americas keynote paper) proposed that a third period started in 1992 with the release of the Digital Chart of the World (DCW).

By looking at some key events and their dates, divided into the three phases as proposed by Estes, it can be seen that the first phase was technologically based -- research and development of the budding technologies that will lead to the abilities to create and use global scale data. The second phase, 1960-1990, is a stretching of the limits -- how far can the technology be pushed. And the third phase is taking the lessons learned from Phase 2, and applying the results to solving problems, such as sustainable development (Agenda 21), climate change (Kyoto Protocol), and creation and validation of global datasets. What follows is a review and discussion of some of the relevant events and products from these phases of development and implementation as applied to Global Map, UNEP/GRID, and EROS Data Center data sets, and the user information collected.

Table 1 Summary of key events

Date	Event
	First Phase
1827	First photograph taken
1858	First aerial photograph from captive balloon taken
1891	International Map of the World proposed
1906	First aerial photograph from a rocket taken
1946	ENIAC
1951	UNIVAC 1
1957	SPUTNIK launched
	Second Phase
1960	TIROS 1 launched
1969	ARPANET created
1971	Intel 4004 chip developed
1972	Landsat 1 launched
1973	ARPANET goes international
1975	Landsat 2 launched
1978	Landsat 3 launched
1981	IBM PC introduced

1982	Landsat 4 launched
1984	Landsat 5 launched
1986	IMW officially terminated
1988	IRS-1 (India) launched
1989	More than 100,000 Internet hosts online
	Phase 3
1990	SPOT-2 (France) launched
1991	WWW introduced by CERN; ERS-1 (Europe) launched
1992	DCW released
1994	Global Map proposed
1995	Radarsat (Canada) launched
1996	GSDI established
1997	Kyoto Protocol to the FCCC
1998	IGBP DISCover dataset validated
1999	IKONOS launched
2000	Global Map officially released

The International Map of the World

The International Map of the World (IMW), also known as the Carte Internationale du Monde au Millionème, was the first truly global collaborative mapping effort undertaken. Albrecht Penck proposed the idea at the 5th International Geographical Congress (IGC) in 1891 and was voted on at following IGC meetings in 1893, 1895, 1899, and 1904. The standards to be employed in the construction of the IMW were agreed upon in 1908, and formally accepted in 1909. In 1913, an office, called the Central Bureau, was officially set up in England, hosted by the U.K. Ordnance Survey, to coordinate the IMW project. In 1953, the United Nations, just at the beginning of its existence, took over the project, and placed it under the jurisdiction of the Economic and Social Council. The procedures were reviewed once again in 1962. In 1986, the UN officially terminated the incomplete International Map of the World project (Martin and James 1993; Winchester 1995).

The specifications for the International Map of the World went through several permutations, due to technological innovation and interruptions by two World Wars. The projection to be used was the modified polyconic, bathymetric data were to be shown, place names were to be written using the Latin alphabet in English, with non-Latin alphabet languages translated into the Latin alphabet and the metric system used. After some discussion, the prime meridian was chosen to be Greenwich, rather than Paris. Information to be included in the IMW was population, bathymetry, elevation, roads and railways, and political boundaries. Background on these decisions is practically nonexistent. A large amount of discussion focused on the bathymetry and elevation, it was agreed that "six nations (Brazil, Chile, the Federal Republic of Germany, France, the United Kingdom and the United States of America) should conduct experiments to determine what color tints could be used for the hypsometric and bathymetric layers on the Map" (Department of Economic and Social Affairs 1966). In 1965, the specifications were changed, and a separate projection (Lambert Conformal Conic) to be used for the polar regions was added (Department of Economic and Social Affairs 1966). Over time, different countries used their own national standards to create IMW

sheets. For example, Japan used a slightly different system for contours and tinting than that called for in the IMW specifications. Because of this, many of the sheets do not strictly conform to the IMW specifications, but were accepted as the best available product (Department of Economic and Social Affairs 1965; Department of Economic and Social Affairs 1966; Department of Economic and Social Affairs 1966; Department of Economic and Social Affairs 1969; Department of Economic and Social Affairs 1970; Department of Economic and Social Affairs 1970; Department of Economic and Social Affairs 1975).

Reports were prepared on a fairly regular basis by the United Nations' Department of Economic and Social Affairs on the status of the approximately 2500 sheets of the International Map of the World (Winchester, 1995; Nelson, 1997). It is estimated that in the life of the project, 800 sheets were completed, or approximately 30% of the earth's land surface (Nelson, 1997). In the 1965 report, a copy of the presentation given by H. Ureta, Chief of the Cartography Section of the United Nations Department of Economic and Social Affairs listed several problems facing the IMW project, including a lack of interest by the representatives of some of the largest powers at the time, including the United States. In addition, scientific authorities at the time derided it as a "utopian scheme that could not be carried out because many parts of the world, mainly in Africa and the Americas, were still unknown" (Department of Economic and Social Affairs 1966).

During World War II, the United States produced its own global map to different specifications for an entirely different purpose. This product was the World Aeronautical Chart. "The World Aeronautical Chart is devised primarily as an aid to visual navigation from the air; the features chosen on the charts have a landmark value which is applied to the features selected for inclusion" (Department of Economic and Social Affairs 1969). The targeted audience for this product was the military and later the civil aviation and aeronautics industry. Eventually, it was recognized by the IMW project participants that the WAC and the IMW, despite some overlap, did not highlight the same information, nor present it in the same manner, and therefore, the final decision was that production of both products simultaneously was to be continued.

David Rhind, in the Hotine Lecture at the 1999 Cambridge Conference, presented several reasons for the failure of the IMW project: "lack of commitment of finance to it by those who agreed to participate; conflicts in priority with national objectives in a situation where resources were always limited; the lack of clearly articulated needs which the IMW was designed to meet and demonstrations of success from its use; a lack of clear responsibility for action; the duplication of work given that much of the same material had to be created on different national map projections; concerns over ownership of the results; the exorbitant costs of doing all this in a pre-computer world" (Rhind 1999).

In summary, the International Map of the World was a large undertaking for a world not quite prepared for the effort necessary to create a global map with support and cooperation of multiple agencies, including national mapping agencies. Despite the fact that the final product would have been of use to many people around the world, it simply took too long to complete and therefore was never actually completed. Lessons have been learned, it is hoped, from this exercise. Two that are very important include: it is not easy to get the world to agree to a single standard and that different countries have different objectives (Department of Economic and Social Affairs 1965; Department of Economic and Social Affairs 1966; Department of Economic and Social Affairs 1966; Department of Economic and Social Affairs 1969; Department of Economic and Social Affairs

1970; Department of Economic and Social Affairs 1970; Department of Economic and Social Affairs 1975).

The problems facing the IMW, however, have not disappeared as technological advances have appeared. While desktop computers now make it relatively easy for a user to access and utilize a digital global environmental dataset, the discussions over what information to include, at what scale, and by whom have not ended.

Global Map

Global Map is a product of the International Steering Committee for Global Mapping (ISCGM). The concept for the development of Global Map was originally presented by the Geographical Survey Institute of Japan as a result of the call for global data in Agenda 21, the document resulting from the 1992 United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro. The plan is for a global database that consists of elevation, vegetation, land use, drainage systems, transportation, and administrative boundaries layers. The sources for these data include the Vector Map Level 0 (drainage, transportation, populated places, and administrative units), GTOPO30 (elevation), and the global land characteristics data produced from the 1 km AVHRR land cover data (vegetation, land cover, and land use). An important characteristic of this project is the involvement of National Mapping Agencies/Organizations (NMA/NMOs) and other interested organizations in the production and contribution of data sets and the validation of their accuracy.

Global mapping, as defined by Kunio Nonomura, former director of the Geographical Survey Institute of Japan, and one of the primary instigators of the Global Map project, is a group of global geographic data sets of known and verified quality, with consistent specifications which will be open to the public, considered a common asset of mankind and distributed worldwide at marginal cost (Nonomura, 1994; Nonomura, 1996; Kidokoro, 1999).

What makes this product unique is the level of active participation and call for additional national mapping organization participation. Below Figure 4 shows the status of participation as of June 2002. There are three levels of participation in the project. These levels are defined as follows:

- Level A: provide and process data for your own country, and assist one or more Level C countries
- Level B: provide and process data for your own country
- Level C: provide data for your country

In addition to the red, green and blue color coding for the level of participation, those countries shown in yellow (corresponding to G in the legend) are those that will be receiving a grant from ESRI's Global Map/Global Spatial Data Infrastructure program and are not yet participating in the Global Map project. Those countries shown in gray have indicated interest in the program but have not determined at what level they will participate.

Level of Participation in ISCGM Global Map Project

As of 7 February 2002

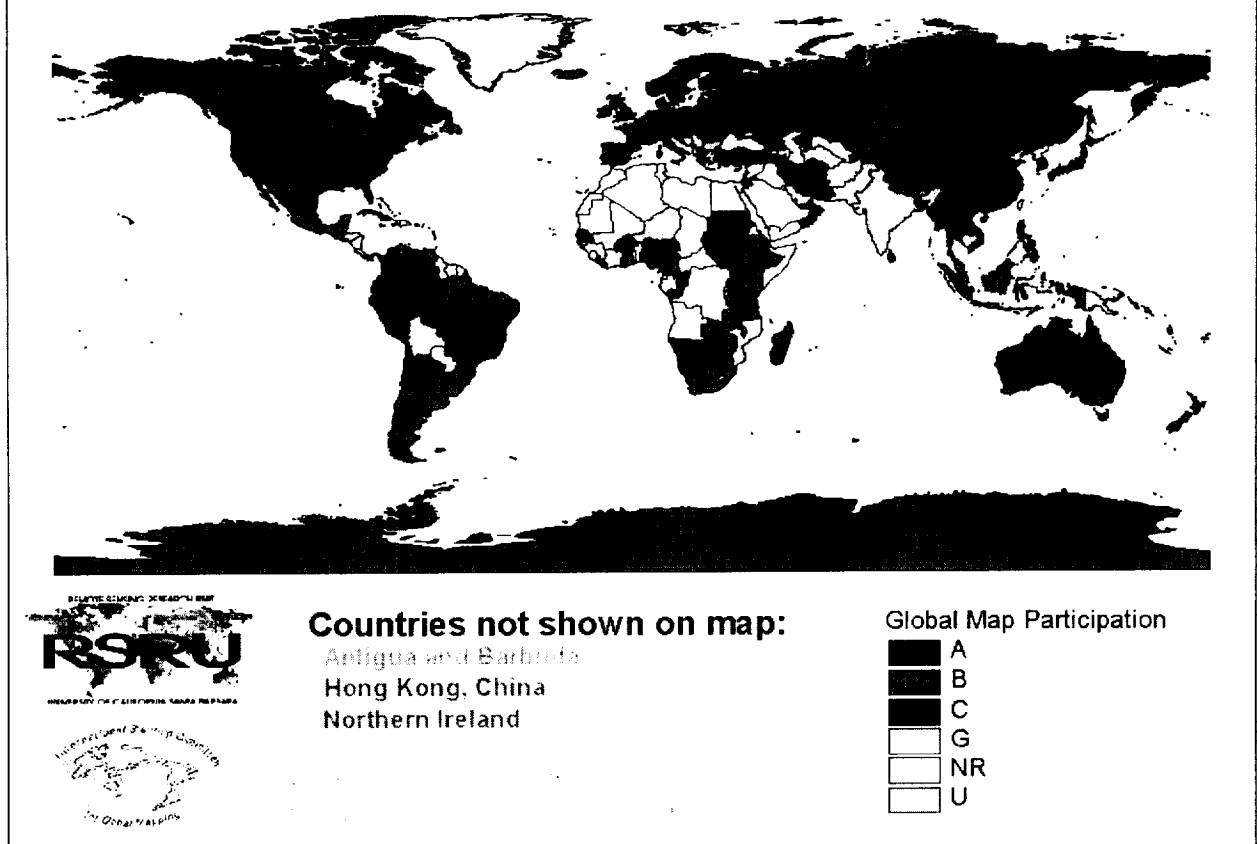


Figure 4 Global Map Participation

In addition to NMOs, several organizations are participating as either full members or observers. SCAR, the Scientific Committee on Antarctic Research is participating as the representative for Antarctica. There was discussion as to whether or not CERCO, the Comité Européen Des Responsables de la Cartographie Officielle, the organization of European national mapping agencies, would represent its approximately 35 members in the Global Map project. The decision reached was that each country would participate on their own, if they so choose. Additional organizations that are represented at ISCGM in an advisory capacity include the United Nations and the United Nations Environment Programme, the United Nations University, the National Geographic Society, the International Cartographic Association. Liaison status has also been accorded the International Standards Organization (ISO) and CEOS. Other organizations are added to the list as they indicate their interest in participating.

The effort put into this project has been significant. Meetings of the ISCGM have been held since 1994 (Tsukuba, Japan, 1994; Santa Barbara, California, 1996; Gifu, Japan, 1997; Sioux Falls, South Dakota, 1998; Canberra, Australia, 1998; Cambridge, United Kingdom, 1999; Cape Town, South Africa, 2000; Cartagena, Colombia, 2001; Budapest, Hungary, 2002 planned). During this time, several working groups have been formed to focus on specific issues, including standards and specifications. Some of these have subsequently been disbanded, their tasks completed.

Working groups have been formed within the International Steering Committee for Global Mapping to focus on the development of a strategic plan, to develop specifications for the Global Map product, and to develop data policy. These have produced draft specifications and strategic plans, which are being followed by the Global Map project in the creation of the product. To manage the vast amounts of data, a tiling system will be used, with 5° latitude tiles with varying longitude (Secretariat of International Steering Committee for Global Mapping 1998).

Currently, data from the GTOPO30, Digital Chart of the World, and the 1-kilometer global land cover data sets have been distributed to the participating countries. These countries' national mapping agencies will then have the option of validating the data as it currently exists, or contribute more up to date national level data at the 1:1,000,000 scale. Several countries have already provided their data, which were released as Global Map Version 1.0 in November 2000 in Hiroshima, Japan (Laos, Nepal, Sri Lanka, Thailand, and Japan). Since then, the Philippines and Colombia have been released, with approximately ten more soon to be released.

Figure 5 is an example of the Global Map product, presented by Motoyuki Kidokoro at the Cambridge Conference, July 1999.

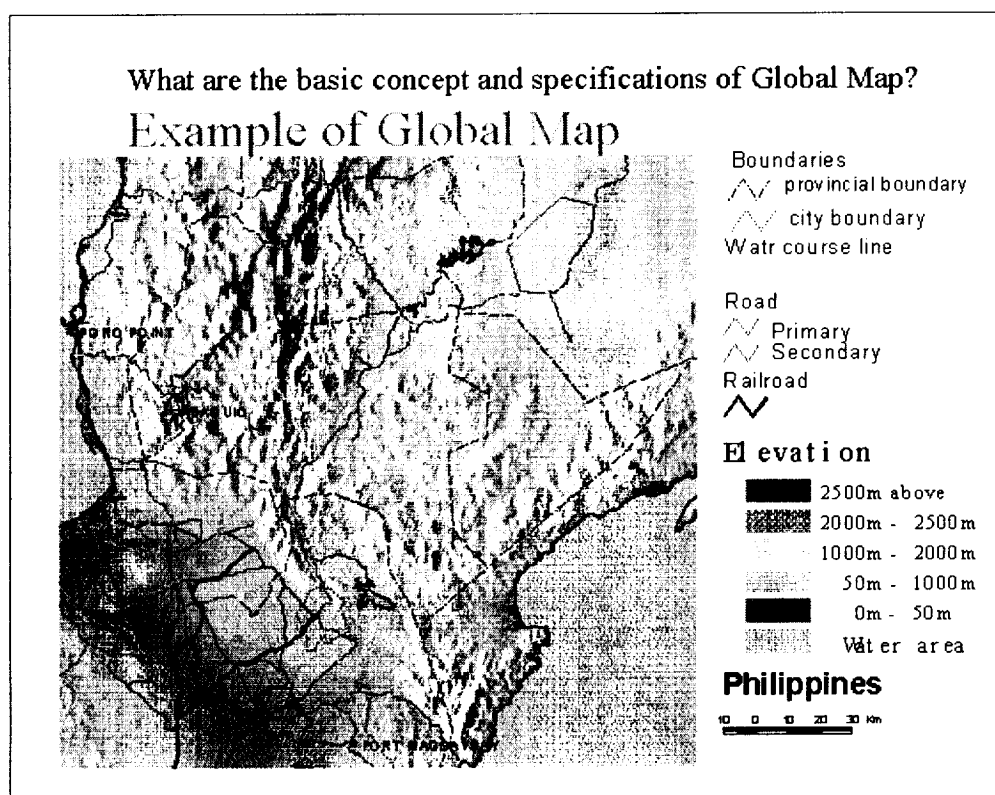


Figure 5. Example of Global Map (Kidokoro 1999)

The Global Map project is the most recent example of NMOs and international environmental organizations cooperating in the production of a global data set. It is hoped that the lessons learned

during the past one hundred years since the International Map of the World was first proposed will, this time, be taken to heart and that this project will succeed, continue and grow in participation.

GTOPO30

GTOPO30 data set is a global raster digital elevation model (DEM) created by the USGS EROS Data Center with cooperation and/or assistance by the U.S. National Aeronautics and Space Administration (NASA), the United Nations Environment Programme/Global Resource Information Database (UNEP/GRID), the U.S. Agency for International Development (USAID), the Instituto Nacional de Estadística Geográfica e Informática (INEGI) of Mexico, the Geographical Survey Institute (GSI) of Japan, Manaaki Whenua Landcare Research of New Zealand, and the Scientific Committee on Antarctic Research (SCAR). The result is a global data set with a grid spacing of 30 arc seconds, or approximately 1 km depending upon latitude (USGS EROS Data Center, 1997).

Sources used for this data set, see Figure 6, include the Digital Terrain Elevation Data from NIMA, the Digital Chart of the World, USGS Digital Elevation Models (DEMs), Army Map Service (AMS) Maps, the International Map of the World, Peru Map, New Zealand DEM, and the Antarctic Digital Database (USGS EROS Data Center, 1996; USGS EROS Data Center, 1997; USGS EROS Data Center, 1997; USGS EROS Data Center, 1999; USGS EROS Data Center, 1999; USGS EROS Data Center, 1999; USGS EROS Data Center, 1999; Verdin, 1999). GTOPO30 will be the elevation layer in the Global Map product.



Figure 6 Sources used to create the GTOPO30 data set (from the GTOPO30 CD-ROM (1997))

Not all the source data have a resolution of 1 kilometer or a scale of 1:1,000,000, although the data have been resampled to 1 kilometer. 1:1,000,000 scale vector data had to be rasterized. Also contour spacing varies from data source to data source. Figure 7 below shows an example of an artifact left over from the generalization of source data and merging together of data from various

sources. As technology continues to improve and data production processes improve, these types of artifacts should show up less and less.

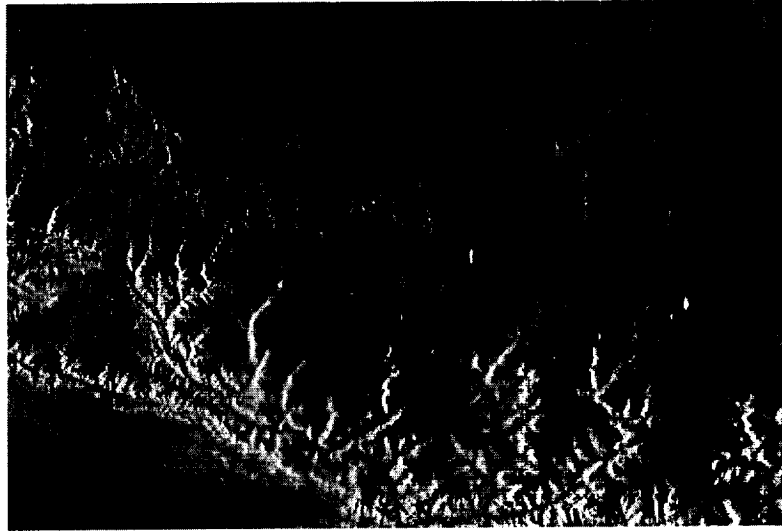


Figure 7 Example of GTOPO30 data showing Nepal. The red arrow points to the area where data of differing spatial resolutions were merged in the production of the data set.

Global Land Cover Characteristics

The Global Land 1-KM AVHRR Data Set Project is comprised of periodic temporal composites of AVHRR and Normalized Difference Vegetation Index (NDVI) data. NDVI is especially useful for vegetation analysis. The USGS EROS Data Center, the European Space Agency (ESA), NASA, the National Oceanic and Atmospheric Administration (NOAA), the International Geosphere Biosphere Programme (IGBP), and the CEOS all supported this effort. The result is a raster database derived from the Local Area Coverage (LAC) from the NOAA AVHRR global land 1 kilometer data set, available via the Internet and on 8 mm tape, comprised of AVHRR channels 1 through 5, NDVI, satellite zenith, solar zenith, relative azimuth, and date index, in the Interrupted Goode Homolosine projection.

Various classification schemes have been used with these data, including Olson Global Ecosystems with 94 classes designed for carbon cycle studies (Olson, Watts et al., 1983; Olson, Watts et al., 1985), the IGBP DISCover (see section below), the Biosphere Atmosphere Transfer Scheme (BATS) with 20 classes designed for land-atmosphere interaction studies (climate models), the Simple Biosphere (SiB) with 16 classes designed for land-atmosphere interaction studies (climate models), Simple Biosphere 2 (SiB2) with 10 classes designed for land-atmosphere interaction studies (climate models), the Anderson land use and land cover system (also known as the USGS land cover legend) with 24 classes (multipurpose), and the Global Remote Sensing Land Cover with 8 classes used for biogeochemical modeling (U.S. Geological Survey, 1993; Eidenshink and Faundeen, 1994; Loveland, Zhu et al., 1999). Additional data sets derived from NOAA AVHRR include the Global Vegetation Index (GVI) with 15 to 20 kilometer resolution, Global Area Coverage (GAC) with 4 kilometer resolution, and Pathfinder with 9 kilometer resolution (Curran and Foody 1994; Loveland, Zhu et al. 1999).

In addition to the data sets listed above, the IGBP-DIS is supporting the development of fire activity data and a global wetlands data set. Both of these will be derived, in full or in part, from the global land 1 km AVHRR data set.

The DISCover data set was jointly created by the U.S. Geological Survey, the University of Nebraska-Lincoln, and the Joint Research Centre of the European Commission. The International Geosphere Biosphere Programme's (IGBP) Data and Information System (DIS) has adopted this particular data set because it fulfills the needs of the IGBP for land cover data. Using Normalized Difference Vegetation Index (NDVI) composites created from the Advanced Very High Resolution Radiometer (AVHRR) from April 1992 to March 1993, a global land cover map with 1-kilometer resolution, and with seventeen classes, has been created on a continent-by-continent basis (Belward and Loveland 1995; International Geosphere Biosphere Programme and Land Cover Working Group of IGBP-DIS 1996; Loveland and Belward 1997; Belward, Estes et al. 1999).

This project was a landmark event. For the first time ever, a global land cover map has been created and validated. Many people from around the world participated in this effort, from collecting the AVHRR data to compiling the data set to the validation. In September 1998, a validation workshop was held in Sioux Falls, South Dakota, in which Expert Image Interpreters used Landsat Thematic Mapper and SPOT data to validate the DISCover data set. Results of this validation exercise can be found in a special issue of the journal *Photogrammetric Engineering and Remote Sensing* published in September 1999.

UNEP/GRID data and sites

Following the 1972 United Nations Conference on the Human Environment held in Stockholm, the United Nations Environment Programme (UNEP) was created with the purpose of providing a programme focus for a Global Environment Monitoring System. In 1985, with more than a decade of experience in collecting, analyzing, and managing environmental data, UNEP established the Global Resource Information Database (GRID) as a focal point for storage, management, and distribution of these data. Moreover, GRID is an element of Earthwatch--the UN system-wide mechanism--which in collaboration with the international scientific community, contributes to the gathering, integration and analysis of data and information to produce comprehensive assessments of environmental states and trends to enable early warnings of environmental threats and to identify policy responses and management options. (United Nations 1992)

UNEP has also played a significant role in the 1992 UNCED meeting, and has since then, become a rather prominent player in the global environmental arena. GRID, a subcomponent of UNEP, was, as noted above, formed in 1985. It is composed of a continually expanding set of regional nodes. There are currently fifteen UNEP/GRID sites in existence, each with a different emphasis, both regionally and scientifically.



Figure 8 UNEP/GRID Center Locations

Table 2 UNEP/GRID Centers and their responsibilities

GRID Center	Regional Emphasis	Science Emphasis	URL
Arendal, Norway	Poles, Nordic countries	Policy and decision-making	http://www.grida.no/
Bangkok, Thailand	Asia Pacific	Capacity building, data management, assessment	http://www.eapap.unep.org/index.cfm
Budapest, Hungary			http://www.gridbp.ktm.hu/
Christchurch, New Zealand			
Geneva, Switzerland	Europe, globe	GIS and image processing	http://www.grid.unep.ch/
Kathmandu, Nepal	Hindu Kush Himalaya	Mountain ecosystems	
Moscow, Russia			http://gridmsk.infospace.ru/
Nairobi, Kenya	Africa, Mediterranean, west Asia		
Ottawa, Canada			
Sao Jose dos Campos, Brazil	Amazon basin		http://www.grid.inpe.br/
Sioux Falls, USA	Globe	Validation of data; global change research	http://grid2.cr.usgs.gov/
Tbilisi			
Tsukuba, Japan	Japan	Technical support, technological development	http://www-cger.nies.go.jp/grid-e/index.html
Uppsala			
Warsaw	Eastern Europe		http://www.gridv.pl/html/index1.htm

User Models

“User modeling involves inferring unobservable information about a user from observable information about him/her, e.g., his/her actions or utterances” (Zukerman and Albrecht 2001). In

other words, creating a model, or description, of a user community by observing and analyzing information about them. In this particular case, the data are collected via the internet. According to Webb et al., there are four types of user models:

1. The cognitive processes that underlie a user's actions;
2. The differences between the user's skills and expert skills;
3. The user's behavioral patterns; or
4. The user's characteristics (Webb, Pazzani et al. 2001).

EOSDIS User Model

As far back as 1995, there has been interest in "who" the user community is for a variety of products. In fact, NASA was interested in discovering who the potential users were of its planned EOSDIS series of products based upon recently and soon to be launched satellites and sensors. For this effort, a group of representatives for each target audience was brought together to discuss what the potential uses of these products might be for them. These groups (and the respective chapter titles of the report) were: Retrospective Research; Field Campaigns and Individual Data Providers; Persistent Information Production for Research; Scientific Environmental Assessment; Commercial Users; Operational Users; Resource Managers and Planners; Policy Formulation and Decision Making; Use of EOSDIS Data and Information Products by the Legal Community; K-14 Educators and Students; Collegiate and Professional Education; and Libraries, the Press, and the Public (Butler, Estes et al. 1998). Below is the table from the document summarizing the results of the groups' discussions.

Table 3 Summary of EOSDIS User Model Effort (Butler, Estes et al. 1998)

User Group	User Population ¹	Use Intensity ²	User Resources ³	User Activities ⁴	Desired EOSDIS Functionality and Capabilities ⁵
Retrospective Research	Broad (1-5)	Medium (>100)	High/High	General	Some changes desired
Field Campaigns and Individual Data Providers	General (1-5)	Low (>100)	High/High	General	Some changes desired
Persistent Information Production for Research	Specialized (<50)	High (1-5)	High/High	Focused	Some changes desired
Scientific Environmental Assessment	Specialized (1-5)	High (1-5)	High/High	Broad	Some changes required
Commercial Users	General (1-5)	High (>100)	High/High	Broad	No change required
Operational Users	Widespread (>100)	High (>100)	High/High	Broad	Some changes desired
Resource Managers and Planners	Broad (5-50)	High (5-20)	Medium/Medium	General	Some changes desired
Policy Formulation and Decision Making	General (50-100)	Medium (5-20)	Medium/High	Focused	Some changes desired

Legal Community	General (1-5)	Low (5-20)	Low/Low	Narrow	Some changes desired
K-14 Educators and Students	Widespread (5-20)	Low (20-100)	Low/Low	Focused	Some changes required
Collegiate and Professional Education	Widespread (5)	High (>100)	High/High	Broad	Some changes desired
Libraries, Press, and the Public	Broad (5-100) [Libraries/Press]	Low (5-20)	Low/Low	Broad	Some changes required
	Widespread [Public]				

- 1 User Population: specialized (user population less than 500); general (500-10,000); broad (10,000-50,000); widespread (> 50,000) in x number of user groups given in parentheses.
- 2 Intensity of Use: Demands on EOSDIS (none, low, medium, or high) as well as numbers of different applications within each given in parentheses.
- 3 User Resources: Human resources available (none, low, medium, or high) and infrastructure resources available (none, low, medium, or high).
- 4 User Activities: Narrow range of user activities (few in number); focused (some/specialized activities); general (more/diverse activities); broad (many activities).
- 5 EOSDIS Functionality: No change necessary; Some changes desired; Some changes required; Extensive changes required.

The main conclusions of the EOSDIS User Model Effort were:

1. The EOSDIS potential user community is large and diverse, and has many shared values and needs.
2. Although EOSDIS was designed and is being implemented primarily in support of the Global Change Research community, EOSDIS can potentially support the needs of a broader range of users.
3. The public sector, private sector, non-governmental organizations (NGOs) and academe all have roles in supporting the broader user needs and these roles will change with time.
4. All potential user groups represented at the conference believe they would benefit from EOSDIS.
5. Within its current resource allocation, EOSDIS cannot support all the needs of its potential user community.
6. A variety of current users are supported by existing data and information systems. The use of these systems can and will continue, but these operations may be enhanced by EOSDIS.
7. Awareness and information about the existence of EOSDIS data, information and services is inadequate (Butler, Estes et al. 1998).

GLCC Survey

Another effort to evaluate the user community of a particular product was that of the staff at EROS Data Center for the Global Land Cover Characteristics product. As part of the Special Issue of Photogrammetric Engineering and Remote Sensing (PERS) to commemorate the completion of the

IGBP DISCover land cover data set, Brown et al. reviewed the dataset from the users' perspective (Brown, Loveland et al. 1999). This article reviews the need for peer review and the value of feedback from the users of the data. User feedback was collected in four different ways: information communication, cooperative projects, online user registration forms, and a user survey conducted via email. Between 1996 and 1999, over 650 users registered to download the data. The data collected were then synthesized to produce a report reviewing the global 1 km land cover user community, which is summarized in the referenced article.

European and Asian Remote Sensing Applications

A third user related project was that of Hadley et al. to review the applications of remotely sensed data by reviewing the published literature and conducting interviews with members of the remote sensing community in Europe and Asia (Hadley, Estes et al. 2000; Hadley 2001). A relative ranking of high, medium, and low was assigned to each of the 20 different application areas. Table 4 below provides a summary of these rankings for each of the categories based upon both the interviews and the literature review.

Table 4 Results of Commercial Applications of Remote Sensing Interviews and Literature Review

Category	Ranking	Color Code
Economic Development	Low/Medium	
Urban and Regional Planning	Medium	
Mapping, Charting, and Geodesy	Low/Medium	
Land Use and Land Cover	High	
Agriculture	Medium	
Forestry	Medium/High	
Rangeland	Low	
Emergency Management	Medium	
Transportation	Low	
Geology	Medium	
Weather and Climate	Medium	
Air Quality	Low	
Water Quality	Low/Medium	
Water Resources	High	
Fisheries	Low	
Marine	High	
Recreation and Tourism	Low	
Information and Intelligence	Low/Medium	
Public Health	Low	
Media, Press, and Education	Low	

Methods

The process by which this project will be undertaken is as follows:

- Review the files received from the organizations; add codes and remove personal identifying information.

- Check for consistency in country names and continents.
- Review the applications and place them into the appropriate categories.
- Explore the data using a variety of data exploration tools, such as GeoVista and MS Excel.
- Determine whether there is a statistical relationship between the variables using a χ^2 contingency test.

The first three steps will be conducted using Microsoft Excel. An example of the data consistency check is seen below in Figure 9.

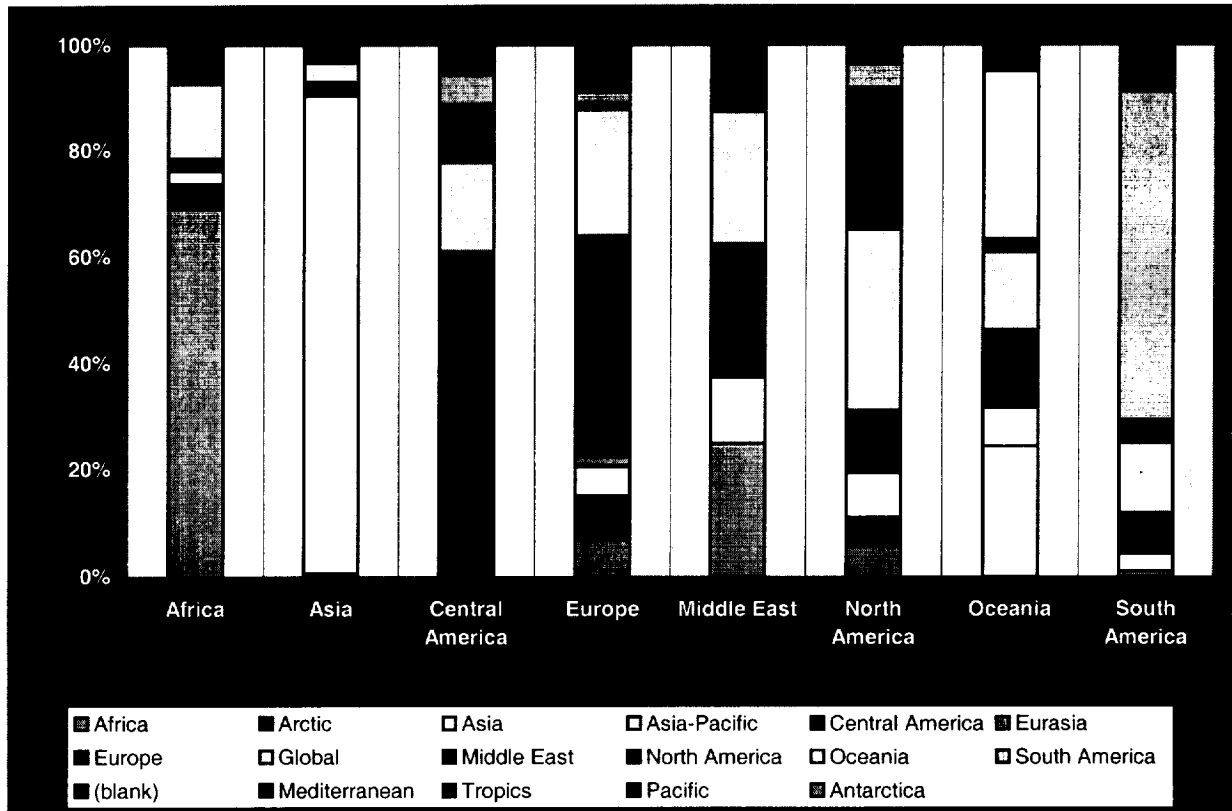


Figure 9 Pivot chart showing researcher location (X-axis) and research location. In this figure, the information has been summarized to show the relationship between the researchers and their research locations by continent for all of the data sets entered to date. For example, Africa based researchers (first column) seem more interested in Africa as shown by the large blue section of the column. This is one example of the exploratory data tools available in MS Excel. This information can be changed by utilizing the pull down menus to restrict the analysis to simply one data set (i.e., Arendal), or by limiting the continents shown.

Besides the options available within MS Excel, the exploratory data software package, GeoVISTA, produced by the GeoVISTA Center at Penn State (Gahegan, Takatsuka et al. 2000). Of particular interest is the Parallel Coordinate Plot (PCP) component of GeoVISTA Studio. A parallel coordinate plot, rather than displaying data on a standard X-Y plot, plots data values on a series of parallel vertical axes, with lines drawn between the different values for a single entry. What results is a visible “signature” for each row in the data set (Edsall paper reference here). See Figure 10 for an example of a single data series entry.

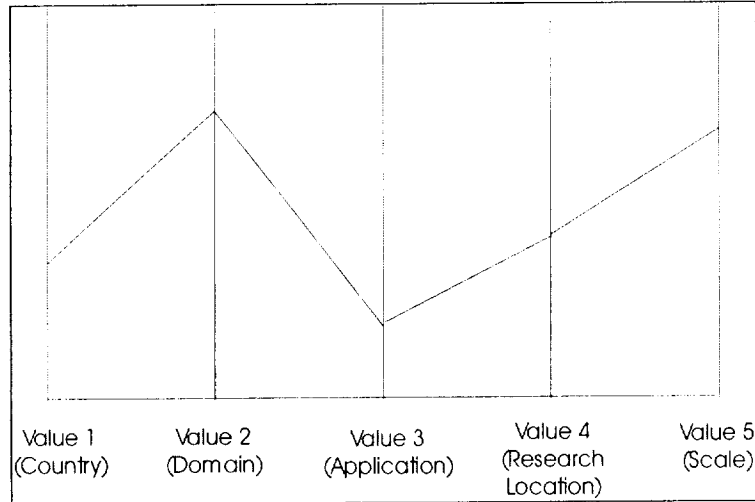


Figure 10 Example of a single entry in a Parallel Coordinate Plot

Following the exploration of the data, a χ^2 contingency test will be used to determine if there is a relationship between any of the variables. In order to test that the variables are statistically independent, a table containing the expected frequencies will be calculated, and a χ^2 value will be calculated. This will establish whether or not there is a relationship between the variables. The next step would be to actually measure the relationship by choosing one of the possible measures: ϕ^2 (Phi coefficient), T^2 (Tschuprow's T), V^2 (Cramer's V), or C (Contingency coefficient) (Clark and Hosking 1986).

Data

The data used for this research are the user information data sets compiled by the EROS Data Center for the Global Land Cover Characteristics data, the UNEP-GRID Arendal user requests, and the Global Map project when users register prior to downloading the data sets. Additional data may be forthcoming from UNEP-GRID Geneva. They have recently restructured their download website which no longer monitors users, but previously archived user registrations may be available [personal communication, Ron Witt, UNEP, May 31, 2002]. This information includes the user's name, address, email address, telephone and fax numbers, their research interests, and the geographical area of interest. From this information, a database was constructed by removing personal identifying information, then assigning a unique identifying code to each entry. This enables referencing capability in case of questions regarding entry information in the future. From the information provided by the EDC, GM, and UNEP-GRID Arendal, these categories were created: USER, DATA SET, DATE, COUNTRY, CONTINENT, DOMAIN, APPLICATION, LOC COUNTRY, LOC CONT, and SCALE.

- USER: the unique identifying code assigned to each individual
- DATA SET: the name of the data set they downloaded (Arendal, GLCC, or GM)
- DATE: the date they registered in yyymmdd format
- COUNTRY: the country they resided in when they downloaded the data set

- CONTINENT: the continent or region where the country is located
- DOMAIN: the user's work location (i.e., government, education, etc.)
- APPLICATION: the application for which the dataset will be used
- LOC COUNTRY: the country location for their research focus
- LOC CONT: the continent or region the country where their research is located
- SCALE: whether their interest is at the local (country level), regional, or global scale

For each user, a 6-digit code was used to allow for cross-reference in case of the need to review a user's entry. This information consists of a two-letter code (one for each of the three data sets – AR, GL, or GM) followed by a four-digit number, entered in numerical order. This code was entered in both the working data file and the original data files (with backups kept of the original documents sent by the respective agencies).

The DATA SET field was used to more easily sort the users of each of the three different data sets in order to compile summary statistics prior to combining all the users. These are Arendal, Global Map, or GLCC, and allow for easier sorting, querying, and sub setting of the data.

The COUNTRY field uses the American English version of the various country names. For example, Brazil is often seen spelled 'Brasil,' and in this situation, for each user from this country, the name was spelled 'Brazil' to ensure consistency and to allow for easier sorting.

CONTINENT information was entered based upon the country, and does not follow the strict seven continents. Rather, several other regions were identified, such as the Middle East, that it was felt were important to separate these users to determine their level of use of these data sets. The online CIA World Factbook is used as a guideline for determining which countries are on which continent.

The domain names used (ACADEMIC, COMMERCIAL, EDUCATION, GOVERNMENT, MEDIA, MILITARY, MUSEUM, NGO, PERSONAL, AND (BLANK)), to some extent, coincide with the internet domain names assigned to various organizations. However, a distinction was made between ACADEMIC and EDUCATION: ACADEMIC implies that this is research level work conducted at the post-graduate level in a university setting while EDUCATION implies K-12 and undergraduate work, mostly consisting of course related projects and homework. MUSEUM was used to distinguish museums from non-governmental organizations (NGO) because NGOs do not necessarily exist to preserve material and information for the use of the public or other patrons. PERSONAL was used to denote those users who registered using an email address from a popular email provider, such as Yahoo.com or AOL.com and who did not provide more information regarding their domain or research applications. COMMERCIAL and GOVERNMENT users tend to have email addresses affiliated with either .com or .gov domains, and were fairly straightforward most of the time. MEDIA was added as a domain more to see if there is a strong media usage of these types of data sets.

The application categories are first entered using the terms the user used when registering and then later sorted into categories using the list utilized by Hadley et al in the commercial remote sensing survey; this list was used as a starting point with other categories created as necessary. The original categories are listed below in Table 5 and were originally created for use in Lawless Potential Commercial Application of EOSDIS Data (unpublished master's thesis) project. This was

considered to be a good starting point rather than creating a new list. This will also allow comparison between the results presented here and those in both the Lawless and Hadley works in the future.

Table 5 Original Application Codes

Application Category	Code
Agriculture	AGR
Air quality	AIRQU
Economic development and conservation	EDC
Emergency management	EMERG
Fisheries	FISH
Forestry	FOREST
Geology	GEOL
Information and intelligence	INFO
Land use and land cover	LULC
Mapping, charting, and geodesy	MAP
Marine	MARINE
Media, press, and education	MPRED
Public health	PUBHLTH
Rangeland	RNGLND
Recreation and tourism	REC
Transportation	TRANSP
Urban and regional planning	URBPL
Water quality	WATQU
Water resources	WATRE
Weather and climate	CLIM

Some additional codes added after reviewing the data are shown below in Table 6. These were created based upon the number of entries that included the relevant terms and the belief that they were not well represented by the original list of twenty application codes. In particular, the Law and Policy category was mentioned in the Hadley work that it was missing, and that much interest has been shown in this category.

Table 6 Additional Application Codes

GPS applications	GPS
Reference	REF
Wetlands	WET
Elevation, topography	TOPO
Soil	SOIL
Modeling (carbon cycle, global change)	MODEL
Software development, testing, demonstration	SW
Research (no other details)	RES
Pollution	POLL
Law and policy	LAW
Archaeology	ARCH

A full description of each category is provided in Hadley, et al. Additional information is given as needed to further define a category.

AGr - Agriculture (Hadley, et al.):

“The *Agriculture* category includes those users involved with the growth, management, and prediction of agricultural products. Users include farmers, agrochemical producers, and commodities traders, all of which depend upon, or make profitable use of, weather prediction, yield estimates, and multitemporal monitoring for various forms of analysis and modeling. The *Manual of Photographic Interpretation* identifies six specific components of agricultural applications: crop identification, crop condition assessment (both biotic and abiotic), farm management, rural development, change monitoring, and research applications. Specific applications include: enforcement of quota restrictions, collecting agricultural statistics, soil properties, and irrigation system engineering/management (Schotten et al., 1995; Abderrahman and Bader, 1992).”

AIRQ - Air Quality (Hadley, et al.):

“The *Air Quality* category incorporates all of the technical functions involved in the process of monitoring and managing air quality at local, regional, and national levels. Monitoring, management, and enforcement of air quality regulations require cooperation between multiple personnel in both the public and private sectors. Environmental policies often require private industries to comply with strict air pollution standards. Various remote sensing techniques have been shown to be useful for the detection and regulation of air quality standards. Specific air quality applications include the detection or measurement of atmospheric aerosols, surface UV radiation, ozone, and actinic flux. European researchers have successfully applied SPOT imagery to calculate the dispersion and deposition of road-generated dust caused by automobile traffic (Keller and Lamprecht, 1995).”

ARCH - Archaeology

CLIM - Weather and climate (Hadley, et al.):

“The *Weather and Climate* category includes users involved with the prediction, analysis, and monitoring of various meteorological phenomenon. The ability to understand and forecast severe weather conditions is fundamental to protection of property and public safety. Specific applications include prediction/detection of fog areas and fog dissipation, prediction of monsoon onset, cloud classification, convective air mass classification and estimations of precipitation and cloud moisture content (Bhandari and Varma, 1996; Lachlan-Cope and Turner 1997; Pankiewicz, 1997; Anthis and Cracknell, 1999; Feidas et al., 2000). The near real-time temporal resolution and coarse spatial resolution of AVHRR data are particularly well suited for monitoring growth and movement of large weather systems in every hemisphere. AVHRR has also been shown to be useful for correlating vegetation with precipitation to define eco-climates (Maselli et al., 1996).”

ECOL - Ecology

Ecological related activities such as assessment, modeling, monitoring, research

EDC - Economic development and conservation (Hadley, et al.):

“*Economic Development and Conservation* consists of any segment of the commercial or public domain that is concerned with developing methods for or planning sustainable economic development (Estes et al., 1994). Of primary concern are the detection, monitoring, and mitigation of environmental impacts caused or magnified by development. Users include: engineering firms, commercial land developers, and various environmental/conservation

groups or agencies. More specifically, the loss of wildlife habitat related to anthropogenic factors is of major concern, because it indicates overall environmental quality. In India, researchers have been using Landsat TM imagery to map potential Sambar (*Cervus unicolor*) habitat in order to evaluate the vigor of various national parks (Porwal et al., 1996)."

EMERG - Emergency management (Hadley, et al.):

"The *Emergency Management* category is concerned with the information technology required to assist decision-makers in the prediction, analysis, and response to natural or man-made crises. Emergency response teams and aid organizations can use remotely sensed data for damage assessment and recovery operations. Natural disasters include, but are not limited to, earthquakes, volcanic eruptions, mass movements (e.g., landslides, avalanches), and severe weather events. Man-made, or man-induced crises include, but are not limited to, warfare, large-scale industrial accidents, and humanitarian operations (post-conflict rehabilitation and reconstruction activities). Remotely sensed data have been used for operational monitoring of marine petrochemical spills, vegetation classification for fire prevention and fuel mapping, and near real-time detection of fire development with the NOAA Advanced Very High Resolution Radiometer (AVHRR) data (Maselli et al., 1996; Airey et al., 1997; Pozo et al., 1997; Pavlakis et al., 1996; Pedersen et al., 1996)."

FISH - Fisheries (Hadley, et al.):

"The *Fisheries* category includes users exploiting marine and freshwater fish resources, as well as the management and analysis of the impacts the fishing industry has on the environment. Users include boat owners, commercial fishing, fish product manufacturers, fishing service suppliers, and fishing trade organizations. Specific applications include the quantification of sea surface temperatures, ocean dynamics, currents, biota, and other relevant parameters (Ramos et al., 1996; Narayana et al., 1995). Nighttime Operational Linescan Systems (OLS) visible-near-infrared channel imagery from the Defense Meteorological Satellite Program (DMSP) has been used to correlate fishing fleet lights with sea surface temperatures. Certain species of fish have been shown to gather at boundary areas between warm and cold currents. OLS composite imagery may provide useful information for monitoring fishing fleets as well as for fishery resource management (Cho et al., 1999)."

FOREST - Forestry (Hadley, et al.):

"The *Forestry* category consists of public and private forest owners, government agencies (e.g., Forest Service), commercial logging operations, wood-products/paper industries, and consulting firms which incorporate the use of remote sensing data for research concerned with the management and/or exploitation of timber resources. Applications include forest stand mapping and inventory, timber harvest planning, stress and disease detection, and estimations of forest biomass, wood volume, and crown size. Foresters use remotely sensed data to classify tree species, locate access roads and property boundaries, determine bearings and distances, and measure areas (Avery and Berlin, 1992; Fazakas et al., 1999). Multitemporal remote sensing imagery can be used for studies of change detection and monitoring of disease and parasite encroachment, as well as the quantification of the extent and severity of damage to stands from wind and salt stress caused by large-scale weather events, such as Hurricane Hugo in September of 1989 (Cablak et al., 1994; Green and Cosentino, 1996)."

GEOL - Geology (Hadley, et al.):

“The *Geology* category incorporates the exploration and extraction activities generally associated with commercial industry active in the management of mining, petrochemicals, and other terrestrial natural resource operations. Mineral extraction includes open-air mining for various minerals and chemicals, terrestrial oil production, and precipitate chemical processing operations. Remotely sensed data is routinely used for identifying and mapping landforms, drainage patterns, structural features such as faults and folds, and rock or lithologic units (Avery and Berlin, 1992). Other geological applications include detection and development of geothermal resources. Furthermore, various environmental organizations have used remotely sensed data for environmental protection, analysis, and mitigation related to ongoing or previous exploitation or extraction activities (Schmidt and Glaesser, 1999).”

GPS

INFO - Information and intelligence (Hadley, et al.):

“The *Information and Intelligence* category includes those users concerned with the collection, analysis, or distribution of remotely sensed data relevant to local, national, and global events or phenomena. National governmental intelligence agencies constitute the most obvious and significant component of this category (Burrows, 1996). Such information gathering and processing agencies make extensive use of commercially available data acquisition systems and derived products. Private information gathering and investigation services are another component of this application category. Information and intelligence users often require data of fine temporal and/or spatial resolution.”

LAW - Law and policy

LULC - Land use and land cover (Hadley, et al.):

“*Land Use and Land Cover* data provides some of the most fundamental knowledge concerning a region’s territory, and are essential to most global change research activities, including assessing current global environmental conditions, and simulating future environmental scenarios that ultimately lead to public policy development (Campbell, 1997; Loveland et al., 1999). The *Manual of Photographic Interpretation* defines *Land Use* as the utilization of land to fulfill human needs, either in a formal economic sense, or in a broader sense of functional relationships among humans, and between humans and the environment. *Land Cover*, in its narrowest sense, often designates vegetative cover, either natural or anthropogenic, or sometimes its absence. In a broader sense, land cover designates visible evidence of land use, to include both vegetative and non-vegetative features – tropical forest, snow or ice, barren land, wetlands, and urban features all constitute land cover (Campbell, 1997).”

MAP - Mapping, charting and geodesy (Hadley, et al.):

“The *Mapping, Charting, and Geodesy* category is concerned with the use of satellite derived data products to develop high quality, accurate cartographic products. A quantitative emphasis is inherent. Scale may range from global to local. Specific applications include terrain modeling/topographic mapping, geodetic surveys, land surveys, and digital mapping. Remotely sensed data can also be useful for the generation of a variety of base cartographic products. For example, specialized cartographic techniques, such as linear feature extraction, can be employed to automatically generate street/road network maps from fine-scale

imagery (Couloigner and Ranchin, 2000). Additionally, the multispectral characteristics exhibited by many electro-optical data acquisition systems allows for the classification of a diverse range of surface types, and can be utilized as a cost-effective method for creating detailed thematic maps.”

MARINE - Marine (Hadley, et al.):

“*Marine* applications are concerned with the research, management, and protection of those marine resources (oceans, coastal zones, salt-water bays, etc.) not included in the *Fisheries* category. Marine activities, such as offshore engineering, port terminal design, or specialized cargo movement are often dependent upon detailed bathymetric and wave climate data. Specific marine applications include studies of ice pack conditions and ice flows, near-shore sediment transport, coastal sea state studies, sea mammal census, ocean color, current, ship classification, sea surface temperature, upwelling, bioluminescence, kelp and other marine plants, detection of marine pollutants, including but not limited to, iron-acid waste, human waste, natural oil and petrochemical seepage, and other phenomena (Bardey et al., 1999; Clark and Boyce, 1999; Cracknell, 1999; Dahdouh-Guebas et al., 1999; Dowdeswell et al., 1996; Space Applications Institute, 2000). Sea ice, which forms regularly during winters in the high latitudes, can severely impact marine traffic and navigation. To keep major ports open for trade all year, Sweden and Finland operate several icebreakers that rely upon synthetic aperture radar (SAR) imagery for information and forecast of sea ice formation, drift, and deformation (Hakansson et al., 1995; Herland and Berglund, 1995).”

MODEL – Modeling

Including carbon cycle modeling, global change modeling

MPRED - Media, press, and education (Hadley, et al.):

“The *Media, Press, and Education* category includes public and private parties utilizing imagery from satellite data acquisition systems to produce visually appealing pictures, maps, and graphics for public presentation, entertainment, art, and journalism. Specific applications include the use of digital elevation models (DEM), as well as imagery, for video games, weather news graphics, and for material in educational textbooks. In K-12, remote sensing imagery is being introduced in a variety of textbooks, and at post secondary and graduate schools, course level applications are central. SPOT data was used in 1988 by NBC News correspondent Fred Francis for his story on chemical weapons production in Rabta, Libya. TM images of the April 29, 1986 nuclear reactor incident in Chernobyl not only provided the world with the first views of the damage, but was also argued by some experts that the use of space imaging forced the Soviet Union to change its policy on what to acknowledge to the world community about the incident (McDonald, 1989).”

Include data evaluation

POLL - Pollution

PUBHLTH - Public health (Hadley, et al.):

“The *Public Health* category includes those users concerned with the protection and preservation of human health. Specific applications include the detection and prediction of vector-borne disease outbreaks, agricultural monitoring for early-warning of famine, targeting of nutrient rich runoffs for testing of toxic dinoflagellates, targeting of chemicals to control *Aedes* mosquitoes in the fight against dengue, location of continual forest canopy

corridors for transportation of yellow fever through monkey populations, and the detection of parasite habitat for ticks, trematodes (*schistosomiasis*), and tsetse flies (Barinaga, 1993; Beck et al., 1994; Epstein et al., 1993; Hay et al., 1997; Hugh-Jones, 1989; Pope et al., 1994; Wood et al., 1992).”

REC - Recreation and tourism (Hadley, et al.):

“The *Recreation and Tourism* category consists of users responsible for planning, development, and management of natural areas that are primarily dedicated to leisure use. Specific recreation applications include service-oriented activities such as sport fishing, guided hunting, and wilderness excursions, as well as large commercial theme parks, regional parks or lakes, natural preserves, and other attractions whose preservation, management, or marketing could benefit from the use of geospatial data (Rigol and Chica-Olmo, 1998). Researchers in Malaysia have used Landsat TM data for the development of new forest recreation areas as well as more intensive management of existing areas (Jusoff and Hassan, 1996). Travel agencies have also used remotely sensed imagery for world wide web vacation planning applications.”

REF - Reference

RES - Research

RNGLND - Rangeland (Hadley, et al.):

“The *Rangeland* category includes those users responsible for the planning, leasing, monitoring, and management of range. The *Manual of Photographic Interpretation* defines *Range* as land that supports vegetation suitable for grazing (Jacoby, 1989; Driscoll et al., 1997). It is any land that supports native and/or naturalized herbaceous and/or shrubby vegetation; it includes natural grasslands, shrublands, savannahs, desert, tundra, alpine, coastal and inland marshes, and, in some instances forested lands. *Rangeland* is naturally and artificially regenerated land areas where herbaceous and/or shrubby species prevail. The land is managed with little input in terms of irrigation or fertilizer or both. Range management comprises range inventory, range monitoring, range condition, and range trend (Driscoll et al., 1997). In addition to active management, there are numerous environmental concerns including biodiversity loss, desertification, unnatural wind and water erosion, and irreparable damage due to overuse (Casimir and Rao, 1998).”

SOIL

SW - Software

Software development, testing, and demonstration

TOPO - Topography

Topography and elevation

TRANSP - Transportation (Hadley, et al.):

“The *Transportation* category includes engineers, consultants, and organizations who are employed in the construction, management, or operation of various public transit facilities (e.g., highways/toll roads, airlines, and railroads). The *Manual of Photographic Interpretation* identifies four components of transportation planning studies: assessment of transportation

corridors, monitoring street conditions, urban traffic studies, and parking studies. Remotely sensed data, especially at fine scales, provides transportation planners complete views of potential routes, as well as information for classification and modeling of potential problem zones (Rao et al., 1993). Of additional concern is the movement of materials (e.g., oil, gas, water, etc.).”

URBPL - Urban and regional planning (Hadley, et al.):

“*Urban and Regional Planning* personnel make critical decisions that impact the environment, socioeconomic conditions, and infrastructure for populated areas. These include, but are not limited to, estimates of urban expansion and population growth, surveying, automated cartographic production capabilities, geographic information systems (GIS) and data base management assistance, and other technical functions required for the urban planning process. Infrastructure issues such as modeling potential runoff to sewer systems, placement of telephone and high-tension power lines, and site selection for telecommunications towers or industrial facilities often require the use of detailed land use or 3-dimensional terrain models (Halounova, 1992; Maathuis et al., 1999). To this end, remotely sensed data is often a cost-effective and efficient tool. Remotely sensed data is also useful for the analysis of raw materials availability, power plant citing studies, and surface fault detection (Katti et al., 1993).”

WATQU - Water quality (Hadley, et al.):

“The *Water Quality* category includes the technical functions involved in the monitoring and analysis of surface and subsurface fresh and coastal water quality. Regulating and observing fresh and coastal water quality is principally the responsibility of public agencies at local, regional, and national levels. Private industry may also be involved as commercial contractors to perform various analysis functions or to participate in the mitigation of polluted or degraded water bodies. Specific water quality applications include pollution detection, mapping water body and watercourse pollutant migration, thermal pollution monitoring, sedimentation concentration estimates, and pollutant runoff detection. Although quantitative water quality measurements often require *in situ* sampling, remotely sensed data can serve as a valuable supplemental data source (Oron and Gitelson, 1996). In particular, thermal pollution is difficult to detect by *in situ* sampling, because many substances rapidly diffuse in water. Thermal remote sensing data is perhaps the best way to monitor thermal plumes and detect point sources (Berghe, 1993; Nelson et al., 1991).”

WATRE - Water resources (Hadley, et al.):

“The *Water Resources* category includes those users responsible for the exploitation, analysis, management, or preservation of water resources. Remote sensing of rivers, lakes, and wetlands is used in specific applications ranging from defining and monitoring flood plains, rates of erosion, wetland extent, and circulation. Hydrologic variables that are potentially available from remote sensing include: soil moisture, snow water equivalent, infiltration, precipitation, soil hydraulic properties, evapotranspiration, frozen soils, surface temperature, and spatial variability within drainage units (Weisnet and Wagner, 1997). Efficient water management is vital to many regions of the world, particularly urban and arid areas. Locating, developing, and monitoring water resources is essential to the support of, or the understanding of, the limits to growth in such areas. In mountainous regions, snow depth and snow extent are critical components of water resource management. Passive microwave

can be used to quantify such parameters due to the ability of the radiation to penetrate cloud cover and snow pack (Saraf et al., 1999).”

WET Wetlands

Some observations made during the coding of the data:

- Vocabulary varies immensely amongst the users and depends on their educational level, area of research, and English proficiency;
- When multiple research objectives or research locations were listed, the first one listed was used for that particular user’s entry;
- CIA World Fact book was used to assist in identifying the continent/region; and
- Dates missing from GLCC data – reviewed email messages and added data to each record prior to entering into working data file, however, not all original email registrations submitted via the EDC website are accessible as of yet.

UNEP/GRID-Arendal

The UNEP/GRID-Arendal user information was supplied by Mr. Lawrence Hislop of the UNEP/GRID-Arendal, located in Norway. The information was supplied in a Microsoft Access database, which was then converted into a Microsoft Excel spreadsheet for coding and removal of personal information. The information contained within this database consists of requests received by UNEP/GRID-Arendal for database products. Table 7 below contains a brief summary of the data, including the total number of entries.

Table 7 Summary of UNEP/GRID-Arendal Users

Total Number of Entries	671		
Number with Researcher Country Clearly Identifiable*	658	Difference of	13
Number with Date Clearly Identifiable*	669	Difference of	2
Number with Scale of Interest Clearly Identifiable*	605	Difference of	66
Number with Domain Clearly Identifiable*	636	Difference of	35
Number with Researcher Continent Clearly Identifiable*	659	Difference of	12
Number with Research Country Location Clearly Identifiable*	605	Difference of	66
Number with Research Continent Location Clearly Identifiable*	605	Difference of	66
Beginning Date	January 4, 2000		
End Date	June 18, 2001		
* The difference is those entries with no information, i.e., blank			

Global Land Cover Characteristics (GLCC)

The Global Land Cover Characteristics user information was supplied by Dr. Thomas R. Loveland, Dr. Jesslyn F. Brown, and Mr. Stephen Howard of the U.S. Geological Survey, EROS Data Center.

The information was supplied in a Microsoft Excel spreadsheet, along with copies of the original emails submitted when users registered and/or responded to a survey. The information contained within this database consists of registrations required prior to downloading any of the GLCC data sets.

Table 8 below contains a brief summary of the data, including the total number of entries. Unfortunately, the date that the registrations were received was not carried over to the Excel spreadsheet. In which case, each registration message has been matched up with the appropriate entry during the coding process. But due to a change in the computer email network at the EROS Data Center, not all the email messages are easily exportable. Therefore, one of the next steps will be to go through each of the survey responses and attempt to match the survey response with the registration information and determine an approximate date. Until that occurs, 431 entries have no date associated with them, with about 300 registrations left to process.

Table 8 Summary of Global Land Cover Users (as of 7 June 2002)

Total Number of Entries	750		
Number with Researcher Country Clearly Identifiable*	750	Difference of	0
Number with Date Clearly Identifiable*	319	Difference of	431
Number with Scale of Interest Clearly Identifiable*	711	Difference of	39
Number with Domain Clearly Identifiable*	705	Difference of	45
Number with Researcher Continent Clearly Identifiable*	750	Difference of	0
Number with Research Country Location Clearly Identifiable*	711	Difference of	39
Number with Research Continent Location Clearly Identifiable*	711	Difference of	39
Beginning Date	February 10, 1999		
End Date	December 17, 2001		
* The difference is those entries with no information, i.e., blank			

Global Map

The Global Map user registration and download log data were supplied by the staff at the Secretariat for the International Steering Committee for Global Mapping, based at the Geographical Survey Institute, Japan. These files consist of multiple Microsoft Excel files, one of which is the main user registration database and the remaining files are individual download logs by country. Due to a change of staff, the condition of the files as they are received varies considerably, and much sorting and cleaning must occur.

When a user registers, they receive an account name and password that they then use to access the download area on the Global Map web site. Whenever a user downloads data using this account name and password, the information from the user registration database is then used to populate the download log, filling in the name, address, and intended use of the data for each file downloaded. A couple of points that need to be kept in mind here: 1) this system leads to huge download logs since each file downloaded is listed as an entry; and 2) once a user has registered, and if they consistently use the same account name and password, the same address and intended use of the data are entered in the download log.

While coding and removing the personal information, the log files are sorted by user name/account name. This leads to a file sorted by the various account names to ensure that a single user with a single intended use is only entered once. Additionally, each country's download logs are kept in separate files, so if a single user downloaded data from multiple countries, they are listed in each country's download log and entered in the master working data file once per country.

Table 6 below provides a brief listing of the countries that have data available and when they were made available. The log files that are currently being coded include those from: Colombia, Japan, Sri Lanka, Nepal, Philippines, Thailand, and Laos. Additional files have been received but have not yet been sorted and coded. These are: Australia, and additional copies of log files for the previously listed countries. The most recently received data files are the raw log files and the raw user registration file. Unfortunately, with the change of staff, these were not exported or formatted as the previously received files. Therefore, some work with the staff at GSI will be required to get all the information in a format that is useful (i.e., dates as dates rather than exponential numbers).

Table 9. Global Map Data Released

Country Name	Country Code	Date of Release
Australia	AUS	June 28, 2001
Bangladesh	BGD	July 22, 2001
Colombia	COL	May 18, 2001
Japan	JPN	November 28, 2000
Laos	LAO	November 28, 2000
Sri Lanka	LKA	November 28, 2000
Mongolia	MNG	December 4, 2001
Nepal	NPL	November 28, 2000
Panama	PAN	March 28, 2002
Philippines	PHL	December 25, 2000
Thailand	THA	November 28, 2000

Included with the Global Map data are the individual files actually downloaded, including the GMViewer program created by the Secretariat to allow for easier viewing of the GM data and the operation manual for this program. The complete download log contains over 25,000 entries. Once sorted and the duplicates entered only once into the master working data file, this number will become much smaller. Also, the downloads of the GMViewer and user manual number in the thousands, and they will not be moved over the working data file, again, significantly decreasing the amount of data that will be used. This master log contains downloads for Thailand, Philippines, Panama, Nepal, Mongolia, Sri Lanka, Laos, Japan, Colombia, Bangladesh, and Australia, which have not been sorted or coded yet.

Table 10 below contains the summary information for the Global Map data as it currently stands, with about 30,000 entries remaining to be sorted contained within the various files.

Table 10. Summary of Global Map User Data

Total Number of Entries	650	
Number with Researcher Country Clearly Identifiable*	649	Difference of 1
Number with Date Clearly Identifiable*	650	Difference of 0

Number with Scale of Interest Clearly Identifiable*	650	Difference of	0
Number with Domain Clearly Identifiable*	634	Difference of	16
Number with Researcher Continent Clearly Identifiable*	649	Difference of	1
Number with Research Country Location Clearly Identifiable*	650	Difference of	0
Number with Research Continent Location Clearly Identifiable*	650	Difference of	0
Beginning Date	November 28, 2000		
End Date	June 11, 2001		
* The difference is those entries with no information, i.e., blank			

3.2.3.2. Global Spatial Data Infrastructure

The Global Spatial Data Infrastructure (GSDI) activity is comprised of a group of individuals representing national mapping agencies, international organizations, and standards organizations. GSDI was defined at the second GSDI Conference (1997) as "the policies, organizational remits, data, technologies, standards, delivery mechanisms, and financial and human resources necessary to ensure that those working at the global and regional scale are not impeded in meeting their objectives."

Personnel from organizations and individuals interested in the establishment of a GSDI first met September 1996 in Bonn, Germany, and focused on "The Emerging GSDI." A second meeting was October 1997, Chapel Hill, North Carolina, and the focus was "Towards Sustainable Development Worldwide." At Chapel Hill, GSDI was defined, as noted above. Also, "one of the central findings of the 2nd GSDI Conference is that the GSDI is of vital importance to implementation of Agenda 21 of the Rio Summit and to multi-national environmental conventions and that it should be placed as central support for decision making before the meeting of the UN Commission on Sustainable Development in 2001. Further, the GSDI is critical to the attainment of substantial and sustainable development in both the developed and developing countries of the world" (1998). The third meeting, in Canberra, Australia, November 1998, focused on the "Policy and Organisational Framework for a GSDI." A primary finding from this third meeting is that "National Mapping Organisations/Agencies play a key role in ensuring that accurate, up-to-date geospatial framework data are developed and maintained. Such data are key to, among others, the promotion of sustainable economic development, improvement of environmental quality, resource management, upgrading public health and safety, modernization of governments at local, national or regional scales, and the responses to natural and other disasters. Therefore such organizations play a vital role in facilitating the development of a GSDI" (1998; Brand 1998). Dr. Estes played a large role in the development of the GSDI concept and the organization. Upon his death, membership in the GSDI Steering Committee passed to Ms. Karen Kline. She has continued to represent both RSRU and the ISCGM on this Committee until late 2002, when a new organizational structure was implemented upon GSDI becoming a formal non-profit organization.

In addition to participation at the GSDI meetings, RSRU personnel have participated in the development of the GSDI cookbook, a document containing information and examples of spatial data infrastructures at various scales, from local to national to regional. These documents can be accessed via the Internet at:

<http://www.gsdi.org/twg/cookbook/index.html>.

Dr. Estes and Ms. Kline also contributed to the Case Studies chapter (Chapter 9), providing information on a variety of other activities around the world.

3.2.3.3. CIESIN Collaboration

In 1999, RSRU personnel were involved in the outlining of a workshop on Remote Sensing and Environmental Treaties: Building More Effective Linkages. This effort was led by the Center for International Earth Science Information Network. During the year 2000, RSRU personnel worked with CIESIN personnel on the production of a background paper titled, "International Environmental Agreements and Remote Sensing Technologies." This paper was made available to the participants before the workshop, December 2000 in Washington, DC. Based upon this workshop background paper, an article was submitted to *Environment* and published in early 2002.

3.2.4. On the Value of Coordinating Landsat Operations

This study presents the rationale in favor of the U.S. Government, specifically the United States Geological Survey, implementing coordinated operations of the Landsat 4, 5 and 7 earth imaging satellites. As a part of this study, we provide a brief summary of the history as well as discuss the current status and direction of the Landsat Program. It is evident that policies, and, in particular, the attempts at commercialization of the program, have kept the program from achieving the expectations of its early proponents in terms of the widespread science and applications use. Programmatic issues, operational costs and data policies have made it difficult, if not impossible, to test the true potential of improved observational frequency to address key science questions related to important ecological issues such as those of global environmental change scientists. The value of coordinated operations stems primarily from increased frequency of observation that would greatly improve the probability of cloud free image acquisition. For a number of research and applications it is critical to acquire imagery at specific times; multiple satellites with coordinated acquisition schedules increase the probability that usable data will be acquired. Our analysis indicates that if the operational use of Landsat satellite data is to become truly widespread, the coordinated operation of two or more satellites will be required.

3.2.5. The California Marine Protected Areas Database: Compilation and Accuracy Issues

The Marine Protected Areas (MPA) GIS database was compiled in 1997 and used to produce maps for a book authored by California Marine Protected Areas. The personnel at the Remote Sensing Research Unit, University of California Santa Barbara Geography Department, performed the GIS work from data sources collected by Debra McArdle. Funding for the compilation effort came from the California Sea Grant Cooperative Extension Program and partially from NASA.

There was no independent accuracy assessment of this database nor were there any follow-up revisions. The database is however the only one of its kind and the creators believe it to be accurate given the data sources used. A 1:24,000 vector database of the coast of California compiled by the State Lands Commission was used as the base layer from which the terrestrial boundaries of the protected areas were estimated. Unfortunately the contiguous coastline at 1:24,000 scale, which

included offshore rocks, is no longer available and no meta data can be found that describes its accuracy but comparison with other data of known accuracy shows that the coastline vectors are highly reliable.

The purpose of this analysis is to make apparent to GIS data users some of the factors of database compilation that may be transparent to managers and decision makers. Of particular interest is the accuracy of this database, how it was compiled and discrepancies in the sources. Acreages and coastline boundary intersections may differ between sources for several reasons but those depicted in the database represent those most accurate possible.

Differences could be due to:

1. Lack of clearly defined source data, including inaccurate boundary descriptions and unintelligible legal descriptions.
2. Unavailability of metadata such as county zoning records.
3. Errors introduced by interpolation and extrapolation from general sketches.
4. Unknown methods used for original source area estimations.

3.2.6. Assessing Landslide Hazard Over a 130-Year Period for La Conchita, California

A landslide consisting of 600,000 tons of mud and silt slid 600 feet down a cliff face and buried nine homes in La Conchita, California on March 4, 1995. The landslide history of this area was considered in the ensuing litigation, which centered on the ranch above the failed slope and whether or not a direct causal link between irrigation and the slope failure could be made. Residents of La Conchita attributed the cause of the landslide to excessive irrigation by the ranch owners. Important for this investigation were the analysis of the naturally unstable geological setting, the unique hydrologic environment of the tectonically elevated bluffs, and unusually high rainfall brought about by El Nino. Establishing the history of landslides in the area relied on historical zoning maps, written accounts of landslides, historic air photo interpretation, digital elevation models, geologic information, and hydrologic analysis.

3.2.7. Remote Sensing and Spatial Metrics for Applied Urban Area Analysis

Traditionally, visual interpretations of high-resolution air photos provided comprehensive information for mapping of urban areas. The basis of data analysis was the interpreter's knowledge of the spatial arrangements of urban land cover features (e.g. texture, pattern, shapes, densities) that were used to characterize socioeconomic features and urban land use structures (Haack et al. 1997). Beginning with the availability of satellite remote sensing imagery in high temporal and spatial resolution, analysis methods became more objective and suitable for application over large areas using temporally consistent datasets.

Some new developments can significantly improve the mapping of urban areas from remote sensing. High-resolution space borne satellite systems such as IKONOS and hyperspectral sensors provide a

more detailed urban area characterization due to the higher spatial and spectral accuracy of the image data. These data are considered to be the beginning of a new era of remote sensing, especially for applications in urban areas. Secondly, innovative image analysis approaches are being utilized that especially consider the spatial and contextual image information for the mapping of land surface features. These approaches consider that the most important urban characteristics are represented in the spatial pattern (e.g. size, density, shape, pattern) of the land cover structures (Mesev et al. 1995, Barnsley and Barr 1997).

In this research, the investigation of urban mapping from remote sensing data will evaluate the use of spatial metrics, defined as quantitative measures of spatial structures and pattern in a landscape (O'Neill et al. 1988). The research will develop a framework for applying spatial metric concepts to remote sensing derived urban land cover maps for description of spatial land cover objects characteristics including their size, shape, density, fragmentation and spatial arrangements. The study is based on remote sensing from traditional sensors such as Landsat TM and air photos and from new and innovative systems like IKONOS and AVIRIS. The datasets will be evaluated and compared to determine their different representations of urban land cover structures. The detailed maps of urban spatial structures derived from remote sensing data provide important information for several applications including urban growth and land use change models. The research investigates the spatial, temporal, and thematic data demands of specific models to provide a parameterization, calibration and validation basis for their application. Furthermore, spatial metric measurements allow a very robust characterization of urban form.

3.2.7.1. IKONOS Data Processing for Urban Analysis

New data resources and innovative concepts in image analysis have the potential for improving the mapping and analysis of spatial urban land use and land cover. Data from new high-spatial resolution satellite sensors IKONOS and QUICKBIRD are available. These data have significant potential for detailed digital imaging of the urban environment. But, due to the higher spatial resolution, it is more difficult to apply traditional digital image analysis algorithms to derive thematic information from these new data. Considering the spatial heterogeneity of urban areas, high spatial resolution (2.5 m – 4 m) sensors represent urban land cover objects in comparatively few adjacent pixels. However, the geometry of the targets (e.g. roof structures, topography) and the heterogeneity of the objects themselves (e.g. roads with cracks or fillings) result in distinct spectral variation within these areas of homogenous land cover. Accordingly, urban land cover characterization from such data should apply an object-oriented rather than a pixel-based image analysis. Object-oriented classification is based on image segmentation and may result in a more homogenous and more accurate mapping product with higher detail in class definition. Furthermore, satellite sensors like IKONOS and QUICKBIRD are relatively limited in their spectral resolution. Considering the spectral complexity of urban land cover, there are specific limitations in the separation of built up and non-built up materials and of roofs and roads and of different roof types. Accordingly, the image classification should include additional information about spatial shape and context. Object-based techniques have shown its potential to consider spatial complexity in the image classification process.

The study is based on 7 individual multispectral IKONOS images (4 m spatial resolution) acquired in spring 2001 covering the Santa Barbara urban area (see Figure 11). The data were acquired on different dates with varying atmospheric and illumination conditions. Ground reference data were

acquired to characterize the field spectral properties of urban surfaces and to develop a basis for the training and validation of the image classification. Field spectra were recorded using an ASD field spectrometer. These data were used to identify the spectral properties of different urban surface categories, for radiometric calibration and atmospheric correction of the IKONOS data. Ground mapping and the selection of classification training and test sites were done by additional low altitude aerial photographic flights and field observations using as a base a digital parcel and building dataset of the study area.

The IKONOS remote sensing datasets were acquired with initial geo-rectification completed. However, an accurate mosaic of the individual images required additional geometric correction. This was done by standard polynomial transformation with 50-70 points per scene. Small portions of the images dominated by topography, the geo-rectification resulted in more locational error than the usual 1-2 pixel uncertainty. As most of the study area is flat, these errors did not justify the effort of a further correction using ortho-rectification.

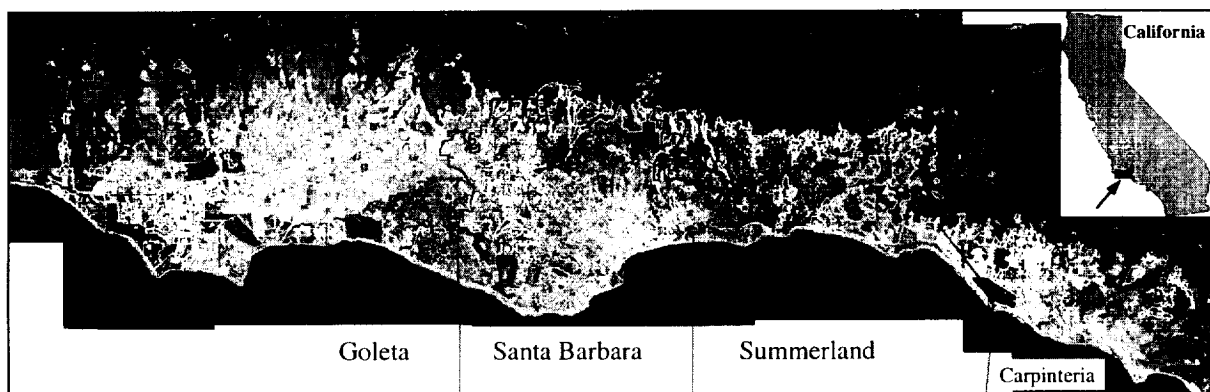


Figure 11: Mosaic of seven IKONOS images (channels 4/3/2) of the Santa Barbara urban area shown with the extent of the urban area mapped from the data (in yellow) and the administrative boundaries of the urban sub-areas (in blue).

The atmospheric correction and reflectance retrieval is a mandatory preprocessing step for reduction of radiometric differences in the images given the differences in acquisition date between the individual images. The reflectance retrieval was based on an image inter-calibration approach to derive the reflectance values for the IKONOS data from ASD field reflectance spectra.

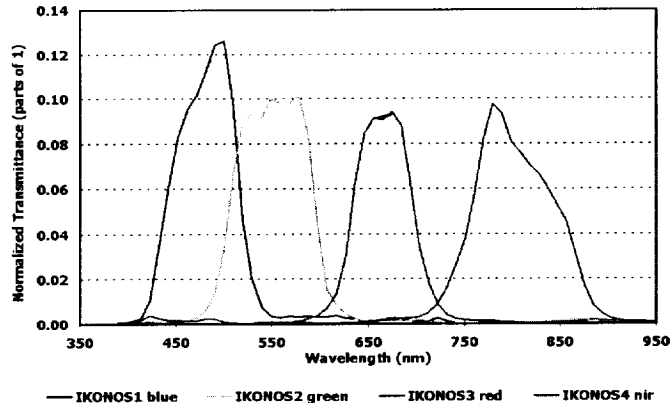


Figure 12: Spectral response function for 4 multi-spectral IKONOS bands in normalized transmittance values convolved to 10 nm increments.

The spectral response functions shown in Figure 12 were used to convolve IKONOS spectra from reference ASD field spectra of specific targets. The IKONOS spectral response functions are available with 5 nm increments from the system operator Space Imaging.

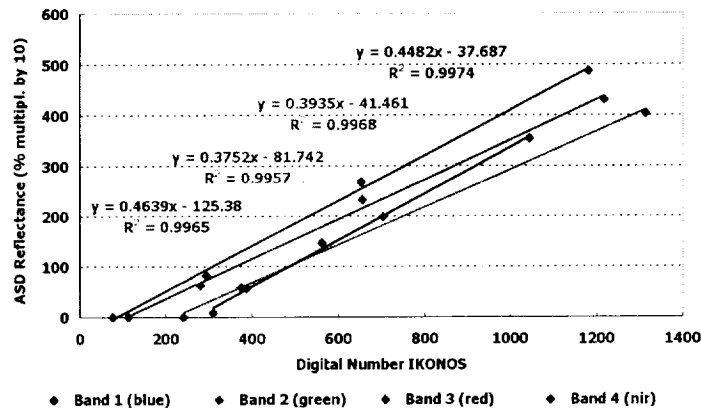


Figure 13: Regression models used for reflectance inter-calibration of IKONOS and convolved ASD field spectra.

The spectral response functions were converted into normalized transmittance values with 10 nm increments (Figure 12), where the value represents the percent contribution of every ASD acquired band (in 10 nm bandwidth) to the signal of the specific IKONOS band. The image was transformed to reflectance using three dark (usually water or shade) and three bright (usually beach or light metal roofs) targets in the #75009 image.

This image covered the Santa Barbara downtown area where most of the field spectra were recorded. The reflectance retrieval applied ASD field spectra convolved to the individual IKONOS channels with a linear regression for each band (Figure 13). The results show a high correlation between IKONOS DN values (in relative radiance) and the ASD spectra with the highest blue band intercept showing the highest atmospheric distortion (primarily due to Rayleigh scattering). The other images were inter-calibrated the corrected image using the overlapping areas and applying a

similar regression method as shown in Figure 3. Finally the seven corrected IKONOS images were merged to a mosaic (Figure 11).

3.2.7.2. Image Segmentation and Object Oriented Classification

The first step in object-oriented analysis with eCognition is a segmentation of the image. This process extracts meaningful image objects (e.g. streets, houses, vegetation patches) based on their spectral and textural characteristics. In e*cognition the segmentation is a semi-automated process where the user can define specific parameters that influence size and shape of the resulting image segments. The resulting objects are attributed not only with spectral statistics but also with shape and context information, relation to neighboring objects and texture parameters. Given a spatial resolution of 4 m typical individual land cover objects (built up structures) are represented by several pixels.

The segmentation was performed by equally weighting of all 4 bands, using the following parameters: Scale 8, Color 0.7/Shape 0.3; Smoothness 0.4/Compactness 0.6. The scale parameter of eight is small but was chosen as most suitable to discriminate smaller targets like residential houses or swimming pools as individual image objects. Diagonal pixels were considered in delineation of the image objects in order to capture roads as linear features. This approach, however, caused some problems in the segmentation of individual houses as they are characterized by compact geometric shapes and were sometimes clumped with adjacent buildings or roads. This is a common characteristic of the segmentation process. The results of the image segmentation are shown in Figure 4. It indicates the homogenization of specific image objects and the accurate representation of individual building structures. The IKONOS mosaic was 500 MB in size. Thus, the segmentation required extensive processing time and sophisticated computer hardware. The following image classification and analysis are based on the segmented image objects, rather than individual pixels. Thus, their processing required significantly less computing resources.

The image classification in eCognition is based on user-defined fuzzy class descriptions based spectral and spatial features. Generally, the program uses a nearest neighbor algorithm, which performs class assignment based on minimum distance measures. The classification process can include a variety of different information, ranging from spectral mean values for each object, to measures of texture, context and shape. The goal of classification was to provide a detailed and accurate land cover product that forms the basis of further analysis of urban structures and refinement of the thematic map towards representing land use and socioeconomic information for specific applications. Accordingly, the definition of the land cover classes had to be based upon the major land cover classes: bare soil, water, vegetation, non-photosynthetic vegetation and built up areas. Built up areas are represented by several different individual classes: for an analysis of spatial urban structure it is important to separate buildings from other classes such as roads, parking lots and swimming pools. Due to the spectral variability of roof targets different roof type classes were assigned for the classification (Figure 4). "Light Commercial Roofs" represent metal and asphalt roofs mainly found in commercial and industrial areas. "Light Residential Roofs" include light composite shingle, tile and gravel roofs with different colors. "Dark Residential Roofs" represent dark colored composite shingle, tile and wood shingle roofs. "Red Tile Roofs" form an individual class due to their specific spectra.

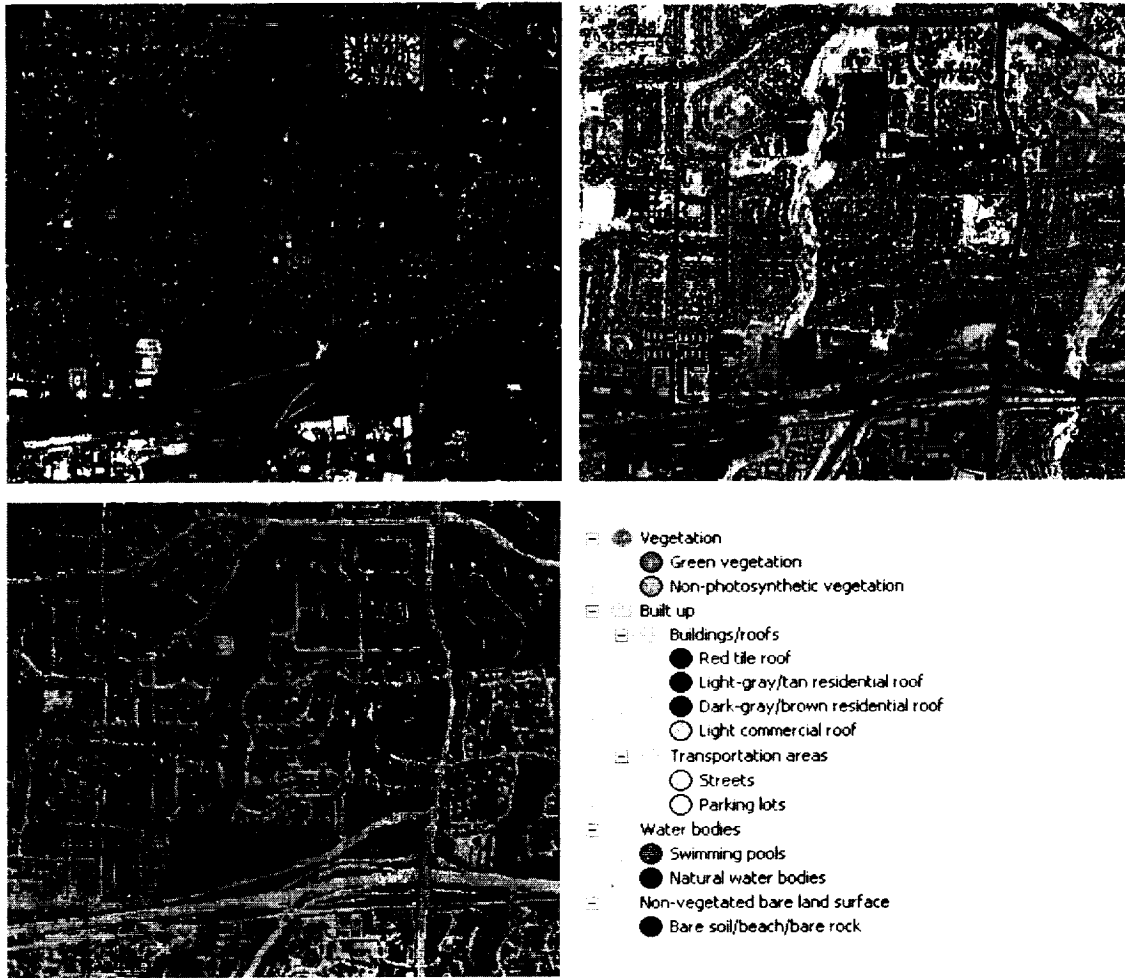


Figure 14: eCognition classification result (bottom) compared to IKONOS false color composite (ul) and digital data representing house and roads overlaid the NDVI.

The spectral characteristics of the classes are presented in Figure 14 showing the vegetation, water and swimming pools with their unique spectra. The other classes, especially the built up targets, have a similar spectral shape and their spectral contrast is mainly due to brightness differences. This shows the limitations of the IKONOS data in separation of those important classes on a pure spectral basis. Accordingly, the classification process also included additional spatial and contextual information in order to evaluate their contribution.

The classification in eCognition was implemented as hierarchical system with Level I classes: water, built up, vegetation and non-vegetated bare land surfaces. The eleven classes used and described before are assigned as Level II and Level III classes. The Level I classes were separated using spectral information (nearest neighbor distance) except for bare soil/beach/bare rock areas which were constrained by a minimum object size to avoid their confusion with specific roof types. Another minimum size rule was applied for water bodies in order to specify additional separation criterion for shadows and swimming pools. The Level II built up class, (Roofs and Transportation Areas) were separated using spectral and shape information. Usually roads are determined by a linear structure whereas buildings have more compact shapes. We used the length/width ratio of objects

to represent this feature in the classification process. The classification of different roof types (Level III classes) applied principally spectral information. During the classification process it was obvious that some classes were not successfully separated. Accordingly some classes were merged: light commercial and residential roofs; parking lots with roads; bare soil with non-photosynthetic vegetation (NPV). Figure 6 shows the final results of the classification compared to a false color composite and digital data layers of buildings and roads. The overall land cover pattern of vegetation, buildings and roads are quite well represented in the classified map. The land cover categories appear as homogenous objects due to the object-oriented approach used for classification, providing a sophisticated and accurate representation of the real world land cover structures.

An accuracy assessment was performed applying the field mapping results and considering one image object as one reference point. The error matrix is shown in Table 1. It indicates a very accurate classification for green vegetation, water bodies and swimming pools. Good results are shown for light roofs, mainly confused with roads (esp. light concrete roads), and red tile roofs that are mixed with bare soil and NPV. The lowest accuracies can be found for dark roofs and roads that are confused with each other. This indicates that including the spatial shape provides good classification results, considering that the spectral separation is poor. However, there is still a fair significant mixing between these important classes, also indicated in Figure 6. Some road segments appear as individual smaller objects and are classified as roofs due to their shape.

Likewise, some large and linear shaped roofs (especially in commercial areas) appear as roads. This result generally reaffirms the aforementioned problem that spatial and contextual measurements are applied as global variables and cause classification uncertainties due to the heterogeneity of the urban built up structure. However, the overall classification results (overall accuracy 79 %) can be considered good and are encouraging for further application of this mapping product.

3.2.7.3. Spectral Properties of Urban Materials

The urban environment is known as a spatially and spectrally complex assemblage of various land cover types including diverse impervious surfaces, vegetation, water, and bare soil, among others. However, as complex the urban environment and as problematic their accurate mapping from remote sensing, there is an equally poor and insufficient current state of knowledge about urban materials and their spectral properties and separation.

User/Reference Class	Green Veg.	Red Tile Roof	Light Roofs	Dark Roofs	Streets/Parking Lots	Swim. Pools	Water Bodies	Bare Soil /NPV	Sum
Green Vegetation	103	2	0	6	8	0	1	3	123
Red Tile Roofs	0	109	0	2	2	0	0	25	138
Light Roofs	0	0	87	0	3	0	0	1	91
Dark Roofs	0	4	0	82	18	0	1	8	113
Streets/Parking Lots	2	1	13	20	86	2	4	7	135
Swimming Pools	0	0	0	0	0	51	0	0	51
Natural Water Bodies	1	0	0	0	1	0	67	0	69
Bare Soil/Non-photosyn. veg.	2	13	2	8	9	0	0	72	106
Sum	108	129	102	118	127	53	73	116	826
Accuracy									
Producer	0.95	0.84	0.85	0.69	0.68	0.96	0.92	0.62	Overall
User	0.84	0.79	0.96	0.73	0.64	1.00	0.97	0.68	0.79

The variety of urban land cover level III classes is a result of different factors. For example, different roofing materials are used as a function of building type, availability, cost and when the structure was built. Besides the general issue of usefulness, roof materials are particularly diverse in material and color based on preference influenced by the surrounding land use and neighborhood socioeconomic characteristics. Other important considerations contributing to urban complexity are material aging processes, atmospheric influences, vegetation fouling and others. Other features that strongly influence the spectral signal from urban surfaces is object structure and geometry. These properties are not represented in the classification scheme and are considered as part of within class variability. Although structure and geometry usually do not change the general spectral properties of the surface material, they can have a significant impact on the signal due to illumination effects. Object geometry relates to shape and orientation, for example roof structure, slope angle, and orientation. With regard to the position of the sun, part of the roofs might be illuminated while other parts are in shadows. Small-scale surface structures like roof tile pattern or road roughness also affect the spectral signal. The stronger the roughness, the more a surface tends to reflect differently in the forward or backward direction relative to the incoming radiation.

Most urban spectra follow a similar general trend where the overall reflectance brightness varies for the different targets and shows the largest dynamic range in the SWIR region. The reflectance is comparatively low for parking lots, dark gray roads, slightly higher for dark gray tar roofs, red gray tar roofs and light asphalt roads and highest for wood shingle roofs and red tile roofs. Some

important reflectance features can be found near 2200 nm where the more strongly reflectant urban cover types show significant absorption features that represent their physical and chemical properties. Examples for those targets are wood shingle roofs and red tile roofs. Figure 2 also shows the spectral similarity between bare soil and urban spectra. Given the spectra shown in Figures 1 and 2, the separation of major land cover types such as vegetation, built up and water seems to be unproblematic whereas bare soil and built up areas show spectral similarities. The VIS and the SWIR II regions show a fair amount of spectral variation and small-scale reflectance features for some urban targets that also might contribute to the separation of specific land cover types. Also, most urban targets have a fair amount of intra-class spectral variation or fuzzy class boundaries, e.g. the classes "light asphalt road" and "dark asphalt road" represent new and old asphalt conditions that can cover all age stages in between with the resulting spectral signature. Intermediate road conditions might be confused with other classes, e.g. dark gray tar roof and light gray tar roof that have the same general spectral signature shape.

3.2.7.4. Spatial Scale in Urban Mapping

Scale--the spatial and temporal dimension of an object or process--is crucial to geographic analysis. Four meanings of scale are often used: cartographic scale, geographic scale, operational scale and measurement scale. For remote sensing based urban area mapping, the spatial extent of the study area defines the geographic scale. Measurement scale is determined by image pixel size or, more typically, the image spatial (or geometric) resolution or "Instantaneous Field of View" (IFOV). In general, the level of geometric detail in land cover representation by remotely sensed data is determined by the spatial heterogeneity of the target land cover structures and the sensor spatial resolution. Different studies have emphasized the investigation of resolution-dependent variables and critical spatial resolutions for the detection and analysis of real world phenomena at different scales.

Remotely sensed data have been applied to the analysis of urban land cover and land use at several spatial scales. Given the regional to global scale the main measurement objective has been the spatial extent of the urban area. Every related study requires a clear definition of what is considered an urban area versus a rural area. In general, the demarcation between urban and rural areas on the edges of cities may not be distinct. The US Bureau of the Census quantitatively defines urban areas based on population, land area and population density, and by spatial arrangement. A second common approach in delineating urban areas from their rural surroundings is by using image-processing techniques based on spectral response. Similar to the urban definitions from administrative data, discrimination of the urban extent from imagery is problematic and requires consideration of cross methodological issues. The problem of defining and discriminating urban and rural land in remote sensing based analysis is highlighted in Figure 15, which presents the various delineations of Santa Barbara's urban extent using different remote sensing sources compared to the urban extent derived from visual air photo interpretation (considered the "true" urban extent). The exaggeration of urban areas in nighttime acquired DMSP is obvious due to atmospheric influences, the coarse spatial resolution (2.7 km pixel size) and uncertainties in georectification. The IGBP-DISCover data set was the first complete global land cover data set developed from remote sensing data and is at a one-kilometer spatial resolution. Urban areas are represented in DISCover in the "Urban and Built Up" category. However, they were not mapped from NOAA/AVHRR data, as was the rest of the dataset. This reflects the difficulty of mapping urban areas at a coarse global scale. Even at the relatively high 1 km DISCover resolution urban areas are characterized by small

extents and fragmented shapes and with an indistinct spectral pattern compared to other land cover classes. The urban areas in the IGBP dataset show a significant under-representation as they were obtained from the Defense Mapping Agency's Operational Navigation Charts generated in the 1950's and 1970's. Considering the problems with the mapping of urban areas at the super-regional and global scale, precise classification remains complicated. However, with new sensor systems like MODIS the super-regional scale mapping of urban areas should be significantly improved in the near future.

The urban areas in the National Land Cover Database (NLCD) were derived from Landsat TM data and include the areas that are built up at a 30 m pixel resolution. The NLCD dataset is a typical remote sensing data product based on pixel-by-pixel digital classification, and represents the physically built up structures rather the actual extent of the urban land use area. Most regional scale analyses focused on a specific urban area have applied data from the Landsat TM and SPOT sensors. The multi-spectral spatial sensor resolution ranges from 20-30 meters.

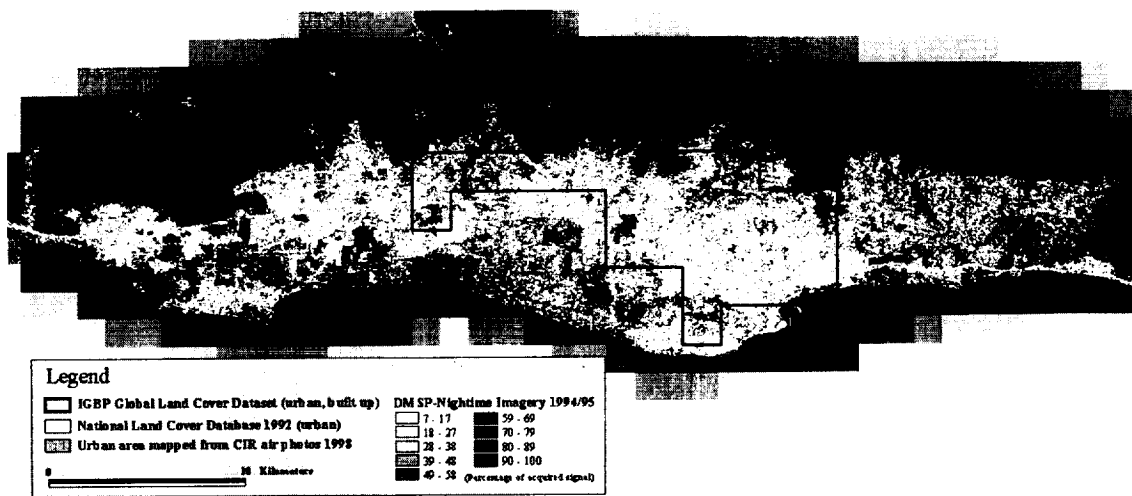


Figure 15: Urban extent of the Santa Barbara/Goleta urban region represented in different datasets compared to the map made by visual air photo interpretation used in this study.

In contrast to the regional and global scales, the primary remote sensing mapping objectives on the local scale are specific land cover objects or map features such as building structures, roads or individual vegetation patches. The accurate mapping of these targets requires higher spatial sensor resolutions. Figure 16 highlights this issue by representing the resolution-dependent representation of high residential built up areas. The blue (dark) graph represents the change in local variance (3x3 neighborhood) as it was derived from Woodcock and Strahler (1987). The peak at 10-15 m spatial resolution shows the areas where the pixel size is about the spatial dimensions of land cover objects in a high-density residential area. The graph in red (light) shows the change in fractal dimension, hence the level of generalization in how built up areas are represented in land cover classification results derived from air photos (3 m resolution, degraded in increments to 15 m), Daedalus scanner data (15 m) and Landsat TM data (30 m). The general decrease shows the increasingly generalized representation of the built up structures as the spatial resolution declines and the shape of the objects are more determined by the quadrangular form of the grid cells and not by real world characteristics. Accordingly, different studies have suggested a spatial sensor resolution of higher

than 5 m for an accurate spatial representation of urban land cover objects such as building structures or urban vegetation patches based on qualitative considerations and experience (Woodcock & Strahler 1987). However, open systematic quantitative investigations of spatial sensor resolution requirements for urban area mapping are still insufficient to date.

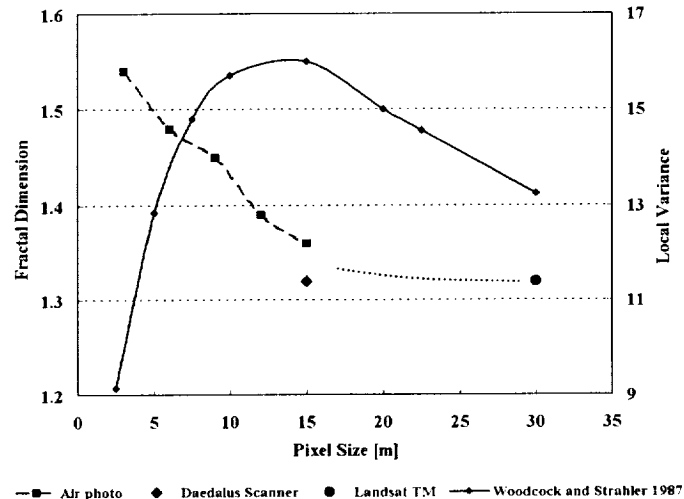


Figure 6: Representation of built up structures in high-density residential areas dependent on spatial resolution shown for analysis using local variance (blue, dark) and for fractal dimension (red, light).

3.2.7.5. Variable Scale Spatial and Temporal Urban Growth Signatures

One major advantage of remote sensing datasets is their availability and consistency over large areas and across historical time series. We seek to provide a unique source of information on how the spatial characteristics of cities change over time. Given those observations and the resulting information about spatial and temporal dynamics, this approach contributes to an improved understanding and representation of how urban areas grow and change as function of scale and differently influenced processes. Examples of analyzing spatial and temporal urban growth dynamics in the Santa Barbara, CA region at different scales are shown in Figure 7. Changes in the urban environment were mapped from historical air photos. Further investigations applied the FRAGSTATS program (McGarical et al. 2002) to calculate spatial metrics for the description and analysis of the growth processes. The example shown at the top of Figure 7 represents the regional urban growth of Santa Barbara from its downtown core area with the largest growth rate in the 1960s and 1970s. The growth started with the allocation of small individual development units in the 1940s and 1950s around the downtown area causing a peak in the urban patch density, an increased number of urban patches and a decreased percentage of the total area covered by the largest patch (the downtown area). Until 1967 more individual urban development patches were allocated, causing a peak in the number of individual pixels and a significant growth in total area (urban sprawl). The decreasing patch density of the total area in the largest urban patches and the mean nearest-neighbour distance indicate a much larger area affected by urbanization than in the years before. By 1976, many individual urban patches had coalesced and formed larger urban areas with higher fragmentation, as shown by the fractal dimension. This trend continues to date, with decreasing fragmentation and a fairly low mean nearest-neighbour distance indicating the loss of open space between the urban areas. The continuous growth in total area equally happens by allocating new

development units and the expansion of existing urban area shown by the fairly stable number of individual patches and the percentage of urban land in the urban core area.

The example at the bottom of Figure 17 shows the change in six different spatial metrics, and indicates the impact of the urban expansion on the landscape structure. The La Cumbre area shows an allocation of new residential development at all parts of the neighborhood between 1978 and 1988. This process of urbanization caused a decrease in individual built up patch density, hence a higher level of spatial aggregation of the built up areas, with a higher variance in size. The complexity of the landscape increased significantly, as shown in the decreased contagion and the higher edge density. The fractal dimension indicates the greater degree of fragmentation of the built up areas as a function of the growth and spatial aggregation. The Isla Vista area showed a change in landscape structure caused by the further development of individual units in residential areas. The result is a more dense residential land use. The growth pattern shows a similar trend in the first three metrics than that indicated for the La Cumbre area. However, the contagion, the edge density and the fractal dimension all show significant differences in the impact of the urban development on the spatial landscape structure. The complexity of the landscape and the fragmentation of built up patches decreased due to the disappearance of vegetated areas and the higher dominance of the built up class, including the spatial aggregation of the built up areas.

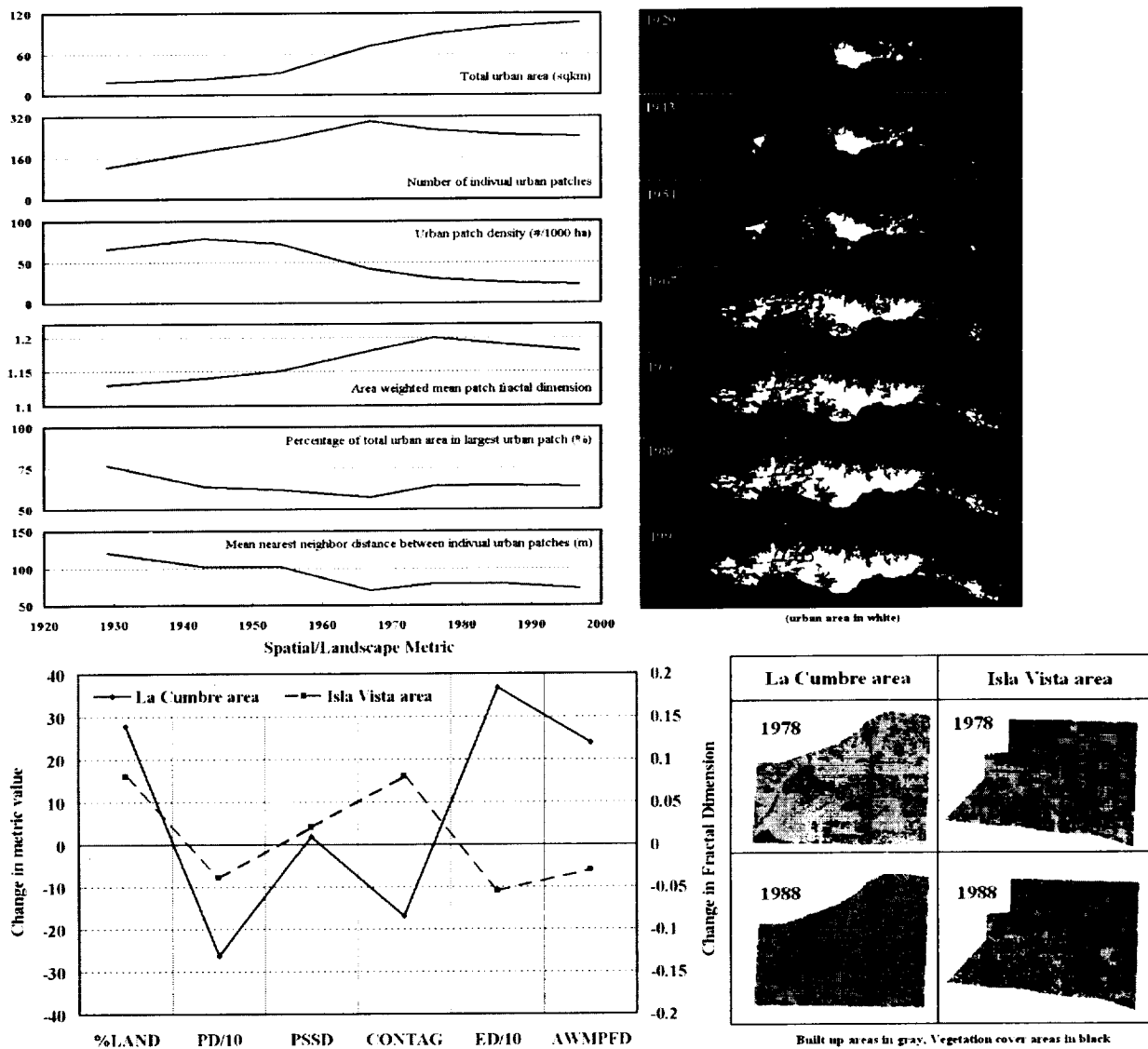


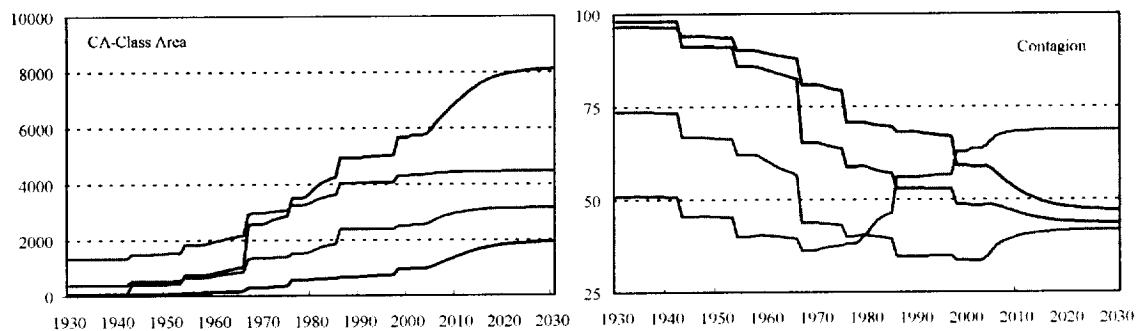
Figure 17: Spatial metrics describing the spatial and temporal growth dynamics mapped from multi-temporal air photos in the Santa Barbara, CA region on the regional scale (top) and the local scale (bottom) (Note: %LAND = Percent of landscape (built up), PSSD = Patch size standard deviation, CONTAG = Contagion index, PD = Patch density, ED = Edge density, AWMPFD = Area weighted mean patch Fractal Dimension).

Considering further investigations and evidence, the changes in metrics over time could be analyzed as more general temporal growth or change signatures representing processes of urban development and land use change and their impact on urban spatial structure. Most studies have followed the deductive view in investigating urban growth processes and have related them to specific consequent structures (from process to structure). The remote sensing based approach investigates the problem by measuring spatial structures and analyzing their temporal changes as the result of specific processes (from structure to process). This perspective incorporates "real world" remote sensing-based measurements of urban dynamics rather than generalized consideration as is commonly used

in theories and models of urban spatial structure and change.

3.2.7.6. Interpretation and Verification of SLEUTH Modeling Results

Figure 18 shows the evaluation of the model results for four sub areas and four spatial metrics. The first diagram, class area (CA), shows that the model gives a fairly good representation of total developed area with a tendency to under predict the amount of growth. Especially in times of the increased growth rates near 1967 and 1986, the graphs indicate a significant trend that underestimates urbanized land. The future evolution in the urban system in the Santa Barbara region indicates the largest amount of growth in the Goleta and Carpinteria area. Both regions offer available areas of vacant land. The CA metric also shows that the further the calibration progresses in time towards the present, the more sophisticated the modeling of the growth area gets. The Contagion indicates the decreasing trend of higher landscape heterogeneity for the sub-areas, except for the Santa Barbara sub-area. The largest jumps between the modeled and measured urban spatial structure are shown for 1967, as the urban landscape became spatially more complex due to suburban sprawl. This reflects the general trend that the model tends to predict urban growth as being too compact. The fairly good simulation of the spatial urban growth pattern can be confirmed by the fractal dimension metrics of the urban patches. All of the sub-areas show a similar high fractal dimension for 1967, the temporal focus of urban sprawl. Since 1976 the fractal dimension values decline for all of the sub-areas except for Summerland, where the growth is increasingly constrained by the topography. The NP metric represented some problems in capturing the allocation of new individual urban patches as part of the urban expansion. Accordingly, significant jumps in the NP metric can be found for 1967 in all areas, the time of the rise in suburban sprawl, and later for Summerland, Goleta and Carpinteria in 1986 and for Carpinteria and Goleta in 1998. The allocation of growth strongly depends on the characteristics or level of urbanization of the local neighborhood of a grid cell (Cellular Automaton). Accordingly, growth has a tendency to expand on existing urban areas, rather than the allocation of new individual urban development. Furthermore, the use of the threshold that 90 of 100 of Monte Carlo simulation runs for each pixel have to confirm the urbanization of the cell, requiring a perhaps too high threshold for initiating new spreading centers. In summary, the model performance can be evaluated as good and appropriate for further analysis. There is a general trend to slightly underestimate the amount of growth and its spatial complexity: the growth in most parts is too compact. Some problems appear in the allocation of new individual development units.



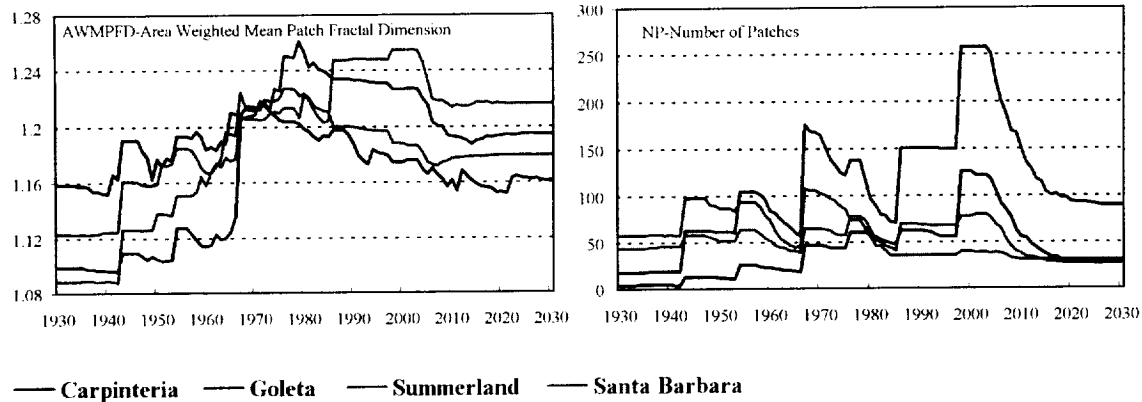


Figure 18: Temporal urban growth signatures of spatial metrics derived from the SLEUTH model results, the model calibration years are 1929, 1943, 1954, 1967, 1976, 1986, 1998 and 2001.

3.2.7.7. Spatial Land Cover Pattern Analysis for Representing Urban Land Use and Socioeconomic Structures

To further analyze and refine the land cover mapping product, we applied a set of spatial metrics to describe the built up structure in the study area and to explore the ability to represent land use pattern and socioeconomic characteristics. Spatial metrics are a useful tool to quantify structures and pattern in a landscape represented in a thematic map or classified data set. They are commonly used in landscape ecology (landscape metrics). Recently, there has been an increasing interest in applying spatial metrics concept in an urban environment, emphasizing the strong spatial component in between objects of urban structure and related dynamics of change and growth processes. Figure 19 shows an example of applying this concept to a thematic subset of classification result in the Santa Barbara region. The spatial metrics were derived from a binary layer of buildings derived from the land cover classification. The metric values for Patch Density, in this case housing density, and Contagion (a measure of landscape complexity) were calculated for a local circular area as spatial domain with 200 meter radius using the program FRAGSTATS. The four maps represent the population density (from Census 2000 block level),

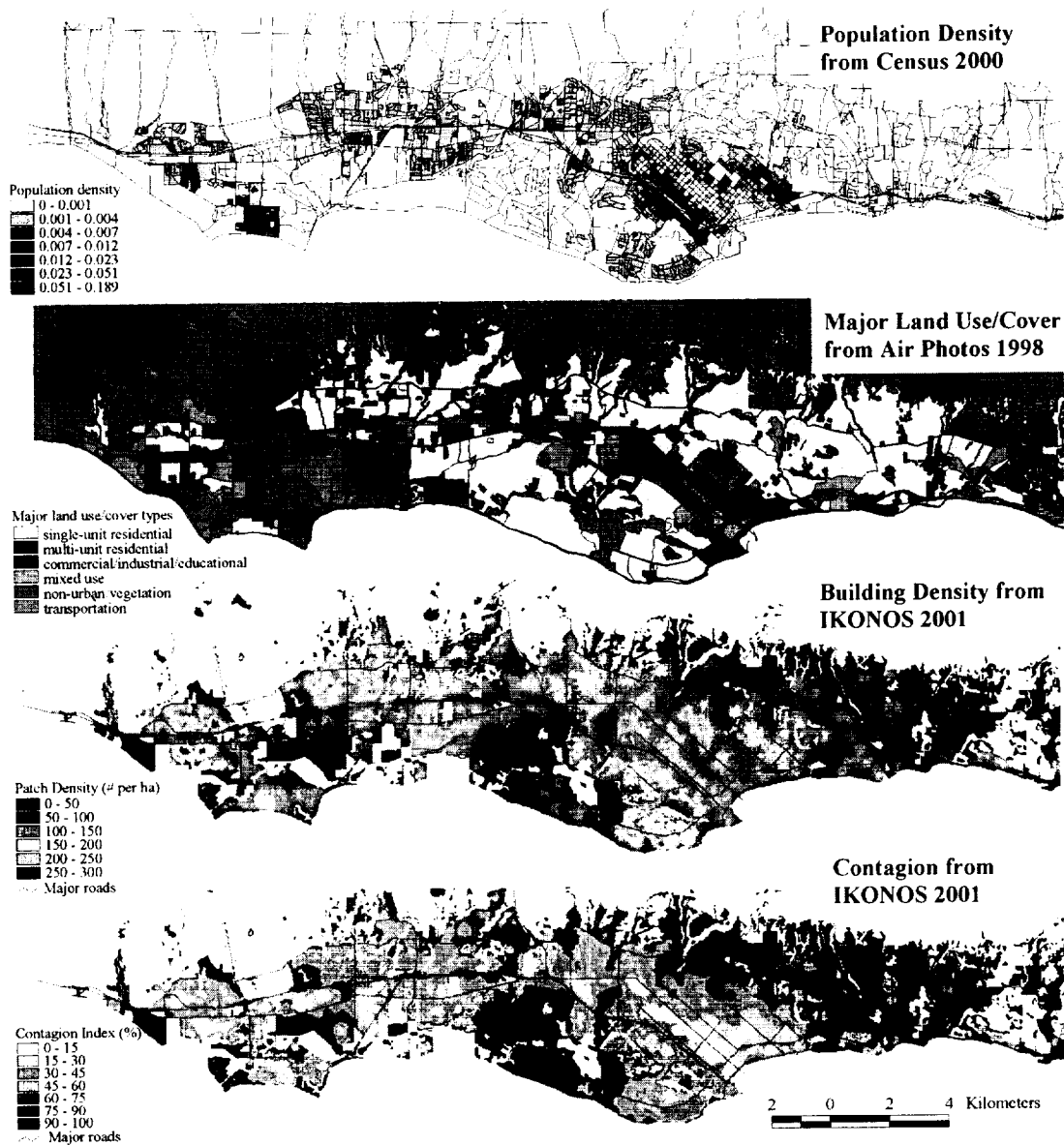


Figure 19: Comparison of the population density (Census 2000 block data) and the major land use classes (mapped from 1998 airphotos) with the spatial distribution of two spatial metrics for the Santa Barbara, CA region.

the major land uses and the distribution of two spatial metrics. Comparing the patch density spatial distribution with the population density distribution, they show a similar pattern with higher population density for increased patch density. The Contagion represents the land use pattern quite well, with high values for low- density residential, intermediate values for medium and higher-density residential and the lowest values for commercial and industrial and highly populated areas.

Although these maps cannot really be compared in quantitative terms due to the different spatial domain upon which they are based (also know as modifiable area unit problem), they clearly show the ability of the approach to represent specific spatial characteristics in urban areas. Given the high spatial resolution of the remote sensing data, it is possible to capture more spatial variability than

traditional datasets such as CENSUS.

3.2.8. Colorado River Flood Plain Remote Sensing Study Support

Under NAG5-10457, support was provided to RSRU researchers to develop and implement a collaborative research program to utilize remote sensing datasets to develop a history of surface water conditions in the Colorado River Delta in the states of Sonora and Baja California Norte, Mexico. This study was undertaken in collaboration with investigators from the Centro de Investigacion Cientifica y de Educacion Superior de Ensenada (CICESE) in Baja California Norte, Mexico.

The free flow of the Colorado River CR to the Delta in the Gulf of California has been blocked by the edification along its path of 10 big dams, in addition to water diversion for irrigation of the Imperial Valley. Water allocation quotas between the neighboring states and México have forgotten the environment. The native wetlands that formerly dominated this region have almost disappeared. The main wetlands in the delta that remain are the Cienega Santa Clara and the Rio Hardy (Figure 20). These important ecosystems host a natural habitat for fauna and flora that need water on a consistent basis to support vegetation. Sufficient water budget has to be guaranteed in order to maintain these natural habitats. In this study, current and retrospective analysis of these wetlands will be addressed through the integration of satellite imagery, spatial data and water flow records of the CR across the Mexico-US border. Selected images of Landsat archive of the Colorado River Delta that were acquired during extreme flooding and drought conditions will be processed in order to estimate aerial extent of the flooding and variability over time. For a current status Landsat 7 ETM and Ikonos 1m color sharpened images will be analyzed.

The objectives of this study are:

1. Estimate the Rio Hardy and Cienega Santa Clara wetlands extents, general condition, and variability as seen from selected scenes of LANDSAT archive 1973-2001, and its relation to the Colorado river discharge through the U.S-Mexico border.
2. Integrate available spatial data of the Colorado River Delta in order to get a better understanding of the wetland region and to support restoration efforts.
3. Establish collaboration with researches from UCSB Remote Sensing Research Unit RSRU and CICESE/UABC into the Colorado River Delta wetland restoration efforts.

MARCH, 1985



MAY, 1990

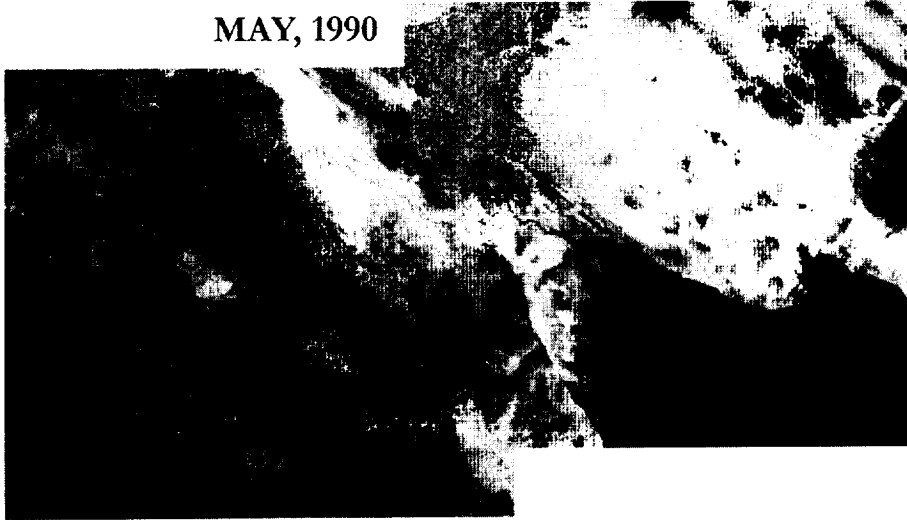


Figure 20. Colorado River Delta study area, Sonora and Baja California Norte, Mexico. Landsat TM image pairs showing wet (March, 1985) and dry (May, 1990) delta conditions.

Progress to date on this study has included:

- Three meetings among collaborating researchers; two in Santa Barbara, CA, and one in Ensenada, Mexico.
- A one-week field visit to the Colorado River Delta region to acquire ground data on hydrology and vegetation in the study area.
- Acquisition of a suite of Landsat TM and ETM, and IKONOS satellite image data covering the study area as well as digital cartographic data, DEM data. GPS locations, and other site specific scientific literature and data.
- Preprocessing and registration of LTM, LETM and IKONOS image data to digital base

maps

Support by NAG5-10457 was critical to developing this study. We anticipate continuing this research and are pursuing additional funding to further develop and expand this study.

3.2.9. African Rainfall Modeling and Assessment

Support on this grant was used to support computer resources for a cluster of projects relating to the study of African precipitation. Specifically, aspects of the data storage, computer software and in-house computer programming have been done using products purchased through this funding source. This section will document the methodology of some of the work related to the African rainfall study.

African populations, more than most other peoples, are dependent on subsistence agriculture for their well-being. Due to underdeveloped infrastructure and irrigation systems many of these farmers rely on rainfall for successful agriculture. Precipitation is highly variable in space and time, creating unreliable agricultural yields. When rainfall is inadequate for a large region the people of that area may experience famine because economies, markets and distribution systems are inadequately developed to respond to such events. Monitoring and forecasting precipitation is therefore a vital component of assessing food security in these regions. Of particular importance is the identification of rainfall anomalies; these abnormalities are indicators of potential food security hazards.

The calculation and identification of rainfall anomalies is an important aspect of recognizing potential food security emergencies. This research is of particular interest to groups such as the Famine Early Warning System (FEWS), who monitor food security in sensitive areas of Africa. One commonly used method for evaluating anomalies is subtracting observed rainfall from the long-term mean to determine if there is an extreme shortage or abundant excess. This method fails to capture the relative significance or probability of occurrence of such anomalies, and the importance of the event may not be adequately realized. With adequate historical data more sophisticated approaches may be used.

Rain gauge networks in Africa are poorly developed owing to political and economic instability. Existing rain gauge derived climatologies lack sufficient temporal resolution and orographic enhancement to be of high value. This has led to the implementation of satellite estimates, but satellite data does not contain a deep historical library, meaning that comparisons with long-term data are difficult. The development of the Collaborative Historical African Rainfall Model (CHARM) – a model combining aspects of historical atmospheric parameters, a digital elevation model, and long-term station climatologies – has provided a data source with adequate spatial and temporal resolution to combat the issues associated with other datasets.

With the development of the CHARM climatology it is possible to fit statistical distributions to the observed data. This innovative approach of fitting the gamma distribution to historical data at each grid cell is unprecedented. A non-parametric test has been employed to test the goodness of fit, validating the use of the gamma distribution for this application.

With gamma distribution parameters calculated at each 0.1 degree gridcell across the continent, anomalies can be expressed as a likelihood of occurrence. This likelihood can be converted to a

standard statistical measurement, the z-score, known in precipitation monitoring as the Standard Precipitation Index (SPI). This allows for anomalies to be understood in both absolute measurement (deviation from mean) and probabilistic (likelihood of occurrence) terms. This will enable food security analysts to evaluate precipitation conditions in a less ambiguous manner.

The statistical solution for rainfall over the African continent using the gamma distribution parameters can give a more meaningful expression of seasonal climate forecasts produced at Regional Climate Outlook Forums in Africa. Forecast tercile probabilities can be used to recalculate the gamma distribution parameters to meet forecast likelihoods. The revised distributions can then be used to translate rainfall values and their likelihood of occurrence. Linking probabilities and accumulation values can result in maps of seasonal rainfall totals associated with given probabilities (e.g. rainfall map of 25th percentile). Conversely, maps of probability of receiving a critical rainfall accumulation can also be derived (e.g. probability map of receiving 400mm). These types of products will convey, in a simpler manner, the implication of a forecast for rainfall dependent activities such as growing crops or determining runoff which may be critical to reservoir levels used in electrical generation.

Background

Africa is a very large continent, containing an area over three times that of the United States. Accordingly, the processes that drive and influence rainfall in Africa are fairly complex. There are a number of resources available that cover the climatology of Africa including a discussion of the pressure systems, major precipitation features and variance throughout the year (Griffiths, 1972; Thompson, 1975; McGregor and Nieuwolt, 1998). The major climatic related feature in Africa is the presence of the Intertropical Convergence Zone (ITCZ). This is an area of heavy precipitation near the equator that oscillates north and south roughly following the zone of maximum incoming radiation.

Understanding the climatology of a continent or regions must be combined with information about the rainfall variation in order to examine extreme rainfall events. Knowledge about the deviations from the norm underscores the potential for catastrophe in any given area. To this end some studies have focused on rainfall anomalies within specific regions. Semazzi and Sun (1997) studied the orographic effects on rainfall in the Sahel and found that large-scale orography is a key component in determining the climate of the Sahel and Guinea coast during summer months. Other studies have analyzed the effects of El Nino/Southern Oscillation (ENSO) events on African precipitation. Ropelewski and Halpert (1987) examined the global implications of ENSO, dividing Africa into its southern and northern halves as separate regions when determining general trends. Nicholson and Kim (1997) took a much more detailed approach, dividing the continent into 90 regions of homogenous rainfall as a method for evaluating the effects of ENSO on precipitation values. In addition, many more focused studies that have been done on specific relationships between sea surface temperatures (SSTs) or atmospheric phenomena and particular regions throughout Africa. Critical studies analyzing these relationships will be reviewed as part of this dissertation.

One difficulty when dealing with environmental data in Africa is the data's relatively poor spatial and historical coverage. This is due to a variety of factors. Africa has relatively few meteorological stations when compared to other, more developed regions of the world. This requires the use of

non-gauge methods of estimating precipitation in order to get a spatially adequate map. In addition to the low spatial density, African rainfall records tend to be temporally sporadic, with gauges having periods where rainfall isn't recorded. Given this relatively poor spatial and temporal record in Africa, it is necessary to look for alternative methods of recreating a rainfall history for the continent.

One way to overcome the lack of reliable rain gauge data is to use temporally dense reanalysis data as an input to physical models that estimate the rainfall based on a number of parameters. The CHARM represents a model combining a digital elevation model (DEM), historical reanalysis parameters and long-term rainfall mean values based on interpolated station data. The reanalysis data provides a historically deep (if spatially coarse) dataset that allows this model to derive daily rainfall values from the last 40 years. The reanalysis data is an attempt to apply current methods and models to historical data (Kalnay *et al.*, 1996).

The first step in this process is to smooth the reanalysis precipitation fields so the resulting CHARM data more accurately reflect true gradients across the surface. The reanalysis atmospheric parameters and DEM data are combined using an orographic model to enhance rainfall fields. The mean values resulting from running the model for all the atmospheric timesteps are then normalized to the best climatological data available to ensure that the long-term means are equivalent at all points on the grid. This historical depth is essential because the increased number of observations at each point allows the statistical parameters to be calculated at each point and fields of the parameters can then be used as input for the SPI or classification algorithms.

This research employs statistical theory common to evaluating many types of environmental and non-environmental phenomena. The modeled precipitation data provides a rich historical time-series, allowing sufficient values with which to fit a statistical distribution. These theoretical distributions can be used to approximate the likelihood of given rainfall events. Using integration it is possible to find a cumulative distribution function, which can furnish the probability of a rainfall event measuring less than any value. For this project it will be important to relate the results of these statistical tests to the farmers, governments and monitoring agencies in meaningful ways, easily interpretable by individuals not trained in statistics or climatology.

Much research has been carried out related to fitting and evaluating statistical distributions to rainfall. Juras (1994) discusses a number of studies that employed several statistical distributions to attempt to fit precipitation data: the compound Poisson-exponential distribution; the log, square-root and cube-root normal distributions; and the gamma distribution. In another such summary, Woolhiser (1992) explores studies applying various normalizing transforms, as well as the kappa and Weibull distributions. The gamma distribution is often used to represent precipitation values for various accumulation periods. Wilks (1990) points out that the gamma distribution provides a flexible representation of a variety of distribution shapes while utilizing only two parameters. Another advantage of the gamma distribution is that it does not include negative values (an impossibility in rainfall accumulation). Nor does this distribution consider values of zero, which can create some problems that must be considered when using the gamma for rainfall analysis. Because of the calculation flexibility and other properties of the gamma distribution it has been chosen as the primary distribution function for this research.

In order to address this problem, this research has been separated into two sections.

The first research section discusses the calculation of the gamma distribution parameters from the CHARM data. Plotting the calculated values on a gridded field results in maps of the gamma distribution parameters. The Kolmogorov-Smirnov (KS) goodness-of-fit test (Wilks, 1995) is then employed to analyze how well the parameters for the gamma and normal distributions reflect the observed rainfall values. This test compares the theoretical cumulative distribution function versus the observed cumulative distribution function to find the maximum difference. When the maximum difference between the two cumulative distributions is minimized the fit is the best.

The second section of this study examines the process of developing maps of normalized rainfall conditions across the continent. These maps will show how observed or hypothetical rainfall accumulations compare to historical values from given locations for specific times of year and duration, based on the theoretical rainfall distribution. Conversely, rainfall likelihood maps can be converted to rainfall accumulations from the probability distribution functions. The translation between rainfall accumulations and probabilities is a critical aspect of this research.

Statistical Fitting, Testing and Analysis

This section presents the mathematical formulas associated with calculating the gamma distribution parameters, methods for testing these parameter values for goodness-of-fit, and potential analysis of these data. The gamma distribution is chosen to fit many environmental variables that are skewed to the right. Many studies have shown the gamma distribution to be a good choice for rainfall data because it uses just two parameters and is bounded on the left at zero (Wilks (1995), Woolhiser (1992), Wilks (1990), Ozturk (1981)). The gamma distribution offers a high level of flexibility with only two parameters: shape and scale.

For this study these parameters are calculated through maximum likelihood estimation. The calculation of the maximum likelihood estimators, as presented in Wilks (1995) and Ozturk (1981), begins with the calculation of an intermediate value A as shown in equation 1. This value is then used to estimate the shape parameter, represented by α . The shape parameter and the mean are then used to calculate the scale parameter estimator, β . Because the gamma distribution does not account for values less than or equal to zero the probability of an event with no rainfall must be treated separately. For this study a mixture coefficient will be used to account for the probability of no rain. This will be explained further in the following section.

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \quad (\text{eqn 1})$$

$$\alpha = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}} \right) \quad (\text{eqn 2})$$

$$\beta = \frac{\bar{x}}{\alpha} \quad (\text{eqn 3})$$

Shape and scale parameters may be calculated at each gridcell based on the historical values for a given period. As an example, α and β parameters for the month of January are shown in figures 21 and 22. These values are based on the 36 modeled rainfall values at each cell, representing the monthly accumulations for January from 1961-1996. These maps show clearly areas such as the ITCZ and the Sahara desert. Analysis of these features will be part of ongoing research.

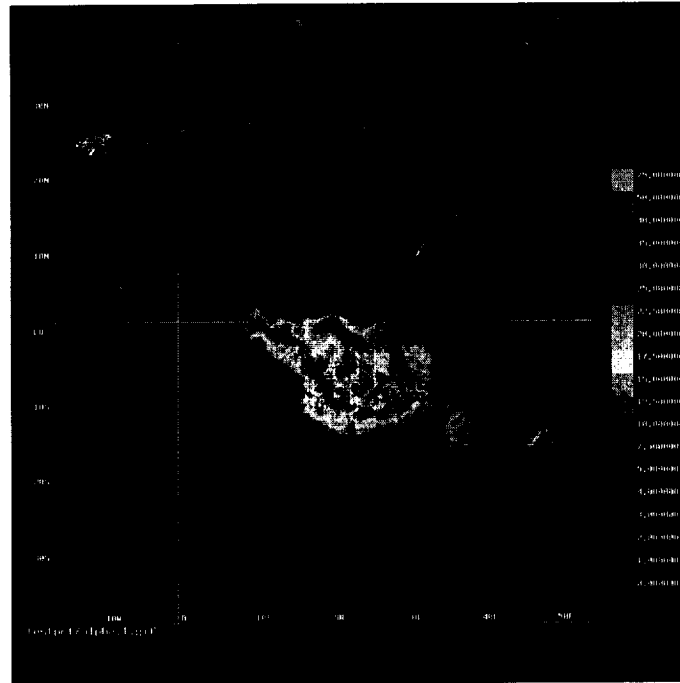


Figure 21. A map of the shape parameter for January based on CHARM modeled rainfall from 1961-1996.

Proper interpretation of the gamma distribution parameters requires a moderate understanding of the distribution properties. Unlike the normal distribution where a single parameter such as the mean or standard deviation can go to great lengths in providing an intuitive understanding, the gamma distribution requires that both the shape and scale parameters be interpreted together. Areas with similar shape values, but different scale values, will have different functions describing the rainfall probability at the different locations.

The shape parameter describes the form of the curve. Distributions with a low shape parameter are positively skewed, and as the shape value increases the distribution curve becomes more normal. Through manipulation of the equations of the gamma distribution it is possible to find that the square root of the shape parameter is equal to the mean of the distribution divided by the standard deviation. In general terms this means that a wet area with relatively small variance will have a large shape parameter, while a dry area with relatively high variance will result in a small shape parameter.

The variance of the gamma distribution is described as the mean multiplied by the scale parameter. Manipulation of this equation reveals that the scale parameter is the variance divided by the mean. So large scale values are the result of relatively high variance in a dry region (low mean), and small scale values are the result of relatively little variance in wet areas.

the observed data is drawn from the chosen theoretical distribution. If the value of the KS test is excessively large then the null hypothesis is rejected and it cannot be assumed that the sample is from the theoretical distribution. This rejection level can be measured by the p-value. If the p-value is sufficiently large then the null hypothesis is not rejected.

As a preliminary test, a subsample of nearly 20000 gridcells was extracted from the African dataset to test the fits of the gamma and normal distributions in order to assess which of these distributions fits the observed data better. The data consisted of monthly accumulations for January extracted from the CHARM 36-year history including 1961-1996. The results show that the gamma distribution adequately fit the observed data, especially when compared with the normal distribution. The gamma distribution could not be rejected at the 0.1 confidence level for over 97% of the non-water pixels in the subsample. This compares favorably with the normal distribution, which could not be rejected at only 33% of the non-water pixels. All this information points to the gamma as being a superior choice for fitting modeled precipitation values to CHARM observances. Further studies using a variety of areas and temporal periods will be undertaken in order to ensure that these preliminary results provide an accurate measure of the goodness-of-fit using the gamma distribution.

Developing the Standard Precipitation Index

The SPI presents a method of normalizing rainfall values to account for spatial and temporal variability over the African continent. The benefits of the SPI result from it being a probability-based model that is spatially invariant and can be scaled to deal with precipitation accumulations ranging from less than a month to multiple years. The SPI offers a standardizing transform that converts a rainfall value to a z-score based on historical values and the probability of occurrence of the observed value. This normalized value introduces an easily understandable method for presenting the status of current precipitation conditions for any time scale.

The SPI was first presented by McKee *et al.* (1993, 1994) as an alternative to the Palmer Drought Severity Index (PDSI). These two were later compared by Guttman (1997), who found the SPI to be a preferred method of precipitation analysis because it is spatially invariant and probabilistic, making it easy to apply to risk management and planning applications. The first step in developing the SPI is to establish the probability density function (pdf) that will be used to approximate the rainfall values.

This study will use the gamma distribution as the approximation to the historical rainfall at each point. Estimating the shape (α) and scale (β) parameters as shown in the previous chapter gives the input to the pdf for the gamma, shown in equation 4. Integrating this equation from zero to any observed value (x) gives the cumulative probability, a measure of the likelihood of rainfall less than or equal to the observed measure. The equation for the integration is shown in equation 5.

$$f(x) = \frac{(x/\beta)^{\alpha-1} e^{-x/\beta}}{\beta\Gamma(\alpha)} \quad (\text{eqn 4})$$

$$F(x) = \int_0^x f(x) dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \quad (\text{eqn 5})$$

One problem arises when using the gamma distribution. The occurrence of no rain for any historical rainfall value is unaccounted for by the gamma distribution in the pdf, however events without rain will be observed during this analysis. There are a number of methods for including the presence of no rain events in the calculations of the probability. Wilks (1990) proposes a computationally complex method involving matrix algebra and iterative solutions that would be difficult to implement with the data volume being used for this study. As an alternative, this study will use a relatively straightforward approach based upon a mixture coefficient, representing the probability of an event of no rain based on the historical data. The number of zeros in the historical dataset is first calculated and divided by the total number of observations to calculate the mixture coefficient, q . A map of the probability of no rain for January is shown in figure 23. Once the mixture coefficient is calculated all values of zero are then excluded from the calculations of the mean, shape and scale parameters. Then, when $F(x)$ has been calculated, the mixture coefficient can be re-introduced as shown in equation 6. $H(x)$ is then the actual probability of rainfall being less-than-or-equal-to the observed rainfall total.

$$H(x) = q + (1 - q)F(x) \quad (\text{eqn 6})$$

Once the cumulative probability is calculated it is transformed to a z-score by a Gaussian transformation. These z-scores correspond to current water conditions in any area, with negative or positive values corresponding to drier or wetter than typical rainfall amounts. McKee (1993) has described z-score ranges corresponding to mild, moderate, severe and extreme conditions. Calculating the z-score for the entire grid results in a map of current precipitation conditions for the entire continent. Figure 24 shows a sample SPI map using a seven-day accumulation of rainfall from the Medium Range Forecast (MRF) global rainfall developed by the National Oceanic and Atmospheric Administration. This global rainfall forecast has been subset and formatted to meet the spatial characteristics of the CHARM dataset. The observed rainfall for this example is the from June 10, 2002 and compares the seven-day forecast from the MRF with the same seven days from the CHARM data. Displaying the results in a mapped product shows the spatial extent, as well as a measure of the severity, of any extreme rainfall events. This product is currently being updated daily and includes maps of the accumulation differences between the MRF data and the historic mean, as well as a map of the MRF accumulation. These products are produced daily and distributed via the internet.

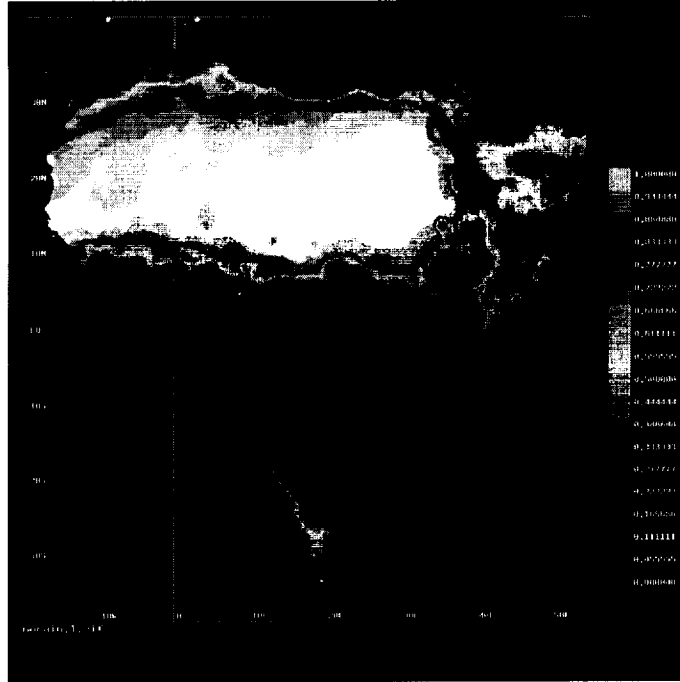


Figure 23. A map showing the probability of receiving no rain for January. Areas never receiving rain during the period appear in blue, and those always receiving rain appear in red.

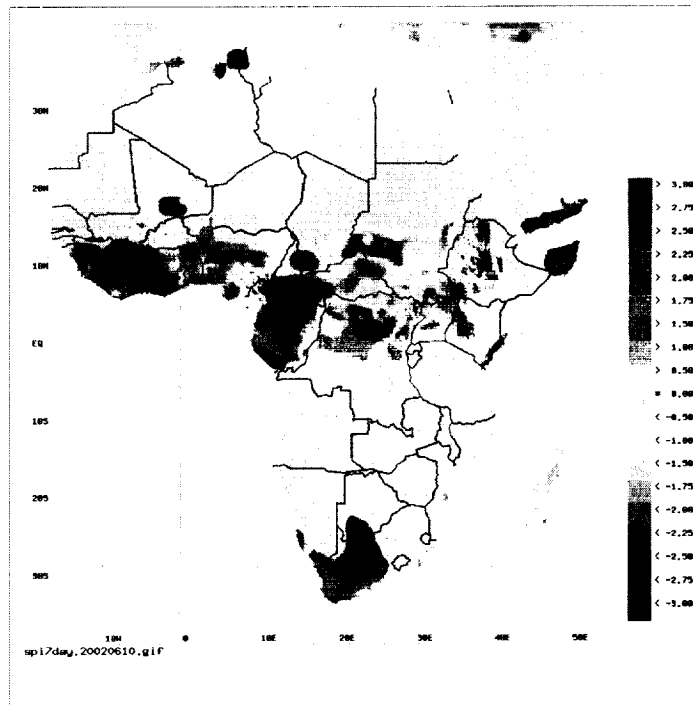


Figure 24. A SPI map based on MRF data for June 10, 2002.

3.2.10. Integration of Remotely Sensed Data and Wildlife Survey to Assess Landscape Scale Habitat Quality

The intent of this research is to focus on the application of aerial and satellite imagery to determining the greater landscape effects on the long-term ecosystem viability. By using field data that not only determines the actual vegetation and land cover type of an area, but also the diversity of wildlife, a map can be generated showing the biodiversity at a given location. Using large-scale Landsat ETM imagery, in conjunction with datasets of roads, buildings, and other human influence analysis can be performed to determine what the proper scale for study on factors affecting local biodiversity is. The study area, the coastal area between Santa Barbara, CA and the northern extent of Vandenberg Air Force Base is commonly referred to as the Gaviota Coast (Figure 25).

Specifically, this study has four goals:

1. Outline landscape scale factors that can affect local biodiversity
2. Provide a high-resolution land cover database of an area presently being considered for reserve status as a National Park, National Seashore, or a State Park.
3. Make recommendations for the minimum size of preserve to protect the biodiversity and endangered species of the area.
4. Establish a replicable methodology for analyzing large areas for best reserve design and placement that accounts for all biodiversity within a minimum area.

The significance of this study is several-fold. The scientific question of how much land is necessary to support the wildlife diversity historically found in area is one of the most pressing questions in modern conservation (Hollander et al. 1995). This study is directly applicable to research in progress conducted by the County of Santa Barbara, and the National Parks Service to locate possible National Parks, National Seashores, and other valuable natural reserves within the Gaviota Coast area. Because the parties conducting research are interested in maintaining biodiversity within the area, and because the County of Santa Barbara is under pressure to develop large areas of the Gaviota Coast for housing, there is a pressing need to understand what the minimum size of reserve need be to protect the sensitive species and diversity found in the area.

Research in the previous years focused on data acquisition and research for proper methods to analyze the acquired datasets. Research generated a series of alterations in methodology from the effort proposed last year. Whereas previously, the intentions of this project were to perform a land cover and metrics analysis on a single Landsat ETM image, it became apparent through the course of researching methodologies and attempting to perform the analysis that this methodology was not comprehensive enough to extract meaningful results from the given dataset.

Automated classification of the ETM scene proved to be inconclusive, so a methodology was derived using a combination of automated classification, aerial photo interpretation, and spatial modeling based on ancillary data. To use this methodology, several additional datasets were gathered. USGS Digital Orthophoto Quadrangles (DOQQs) were collected for the entire study area. These photos, having a spatial resolution of approximately 3m allow for interpretation of land cover

features easily by a trained person. Additionally, datasets of roads, buildings, known streams, and political boundaries were collected for use in the modeling process.

Each of these datasets were given geographic coordinates based on ground control points (GCPs). For this process, a high-accuracy GPS unit was assembled to visit and record locations within the study site that also appeared in the dataset. The coordinates of each location were catalogued and assigned to the corresponding point on the dataset.

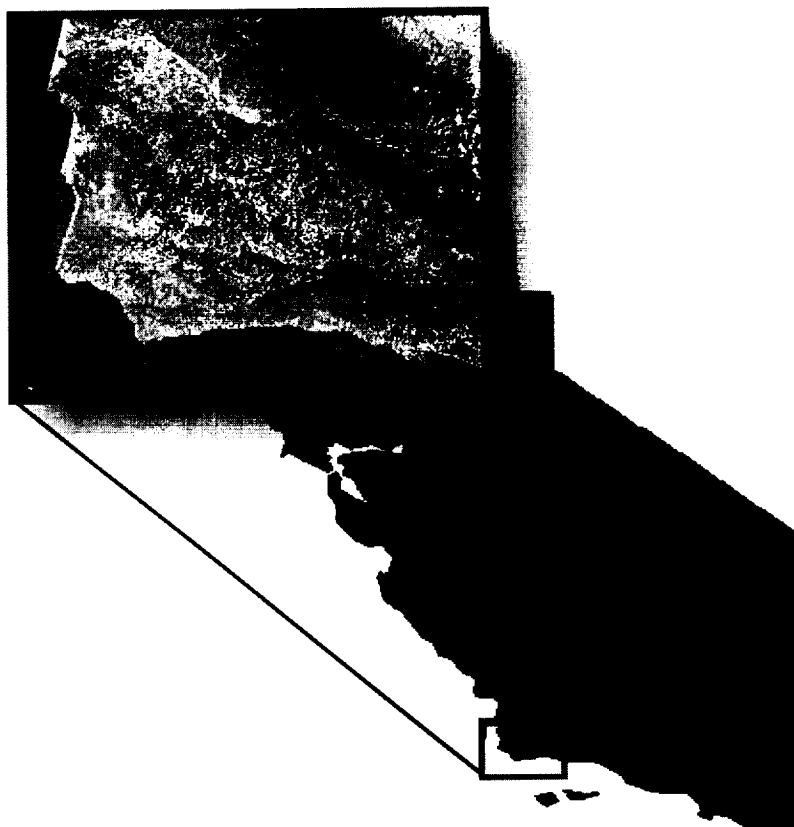


Figure 25.

The land cover classification system was decided on for the purpose of this study. A modified version of the California Vegetation classification suited the area best (Table 1). This classification system, designed specifically for the vegetation of California, is hierarchical and therefore allows the resulting land cover map to describe in as much detail as was obtainable from the datasets.

Research in this last year has clarified the methods for classifying ETM imagery for the purpose of land cover analysis. Additionally, a clear protocol for wildlife sampling has been derived from commonly used bird sampling methods (Gallo et al, 2000). This methodology allows for integration of other field workers' previous and future sampling efforts with this research.

Table 1. Primary Land cover Classification System (Modified from Holland and Keil, 1995)

Level 1 Communities	Level 2 Communities
<i>Marine Aquatic Communities</i>	Subtidal and Intertidal
	Coastal Estuarine
	Coastal Salt Marsh
<i>Coastal Sand Dune Communities</i>	Pioneer Dune
	Dune Scrub
<i>Coastal Scrub Communities</i>	Southern Coastal Scrub
	Sea-bluff Coastal Scrub
<i>Chaparral Communities</i>	Mixed Chaparral
	Chamisal Chaparral
	Manzanita Chaparral
	Ceanothus Chaparral
	Scrub Oak Chaparral
	Serpentine Chaparral
<i>Grassland Communities</i>	Semidesert Chaparral
	Native Bunchgrass
	Valley and Southern Grassland
<i>Closed-cone Coniferous Forest Communities</i>	Non-native Grassland
	Coastal Closed-cone Pine Forest
<i>Mixed Evergreen Forest Communities</i>	Central or Southern California Mixed Evergreen Forest
<i>Oak Woodland Communities</i>	Coastal Live Oak Woodlands
	Valley Oak Woodlands
	Foothill Woodlands
<i>Riparian Communities</i>	Valley and Foothill Riparian
<i>Anthropogenic Communities</i>	High-density Urban
	Low-density Urban
	Cropland

Classification using PCA yielded excellent results in areas that were not heavily shaded due to sun angle and topography. A topographic correction model involving the DEM removed much of the error associated with this phenomenon and allowed for better classification of riparian vegetation types associated with stream channels and incised canyons.

Within the greater study site of the Gaviota Coast, two sub-sites were chosen for avian surveys. The first, an area encompassing three watershed areas on VAFB has historic avian survey data that can be used in support of this research effort from several previous years. The second sub-site is a sample of the urban and natural areas within the city of Goleta. At both of these sub-sites, transects paralleling the streams have been generated and points placed approximately 250 meters apart have been assigned as locations for point survey of birds.

Avian surveys were conducted to generate a database of higher-level faunal diversity during spring and summer of 2001 and 2002. Point surveys of bird diversity, both number of species and number of individuals, yielded quantitative information about the fauna in the study site. This survey method minimizes the chance of surveying the same individual twice. Past surveys of the in the VAFB area have been conducted using this same methodology (Gallo et. al 2000) so results should be compatible for the purposes of the analysis required in this study. This data will then be entered

into a database and used as a quantitative means of evaluating habitat quality. At each location a timed count of the birds species were conducted. These data were combined with concurrent bird abundance data collected by other researchers in the Gaviota Coast area to increase the significance of the research by addressing possible issues of autocorrelation.

Land cover maps were created using eCognition, ArcInfo, ArcView, and Erdas Imagine from two different LANDSAT satellite images of the study site. The two images were chosen to assist in the identification of vegetation by comparing the summer “leaf off” season with the winter “leaf on” season observed commonly in a Mediterranean climate. These maps were designed to describe not only the natural vegetation and habitat, but also human influenced land cover types such as agricultural areas, roads, and buildings. To facilitate the description of some of the finer scale classes, vector data from local government and research were incorporated in to the classification system (Figure 26).

After classification of each study site, the location of each point count survey was overlain upon the map (Figure 27). Each land cover map was then subset to include buffered areas around each point to allow for analysis on the land cover surrounding each point individually (Figure 28). Four different buffer radii were analyzed for significance with respect to observed bird diversity and presence of riparian obligate nesting bird species.

This study has found that while no variable considered in this study could account for all of the variation in observed riparian bird species diversity or richness, the area of riparian vegetation was found to be significant at certain buffer distances. The most significant result was that while the bird surveys only focused on bird species within 100m of the survey point, the greatest correlation between bird diversity and riparian vegetation area (R^2 of 0.52) was found when considering riparian vegetation area within 500m.

This result suggests that while current policy in Santa Barbara County states that a 100ft (30m) buffer of a stream channel to preserve natural vegetation is considered satisfactory to preserve natural vegetation and wildlife when developing an area, this buffer may not create a sustainable riparian community. A change in policy may be required to preserve riparian areas currently not developed.

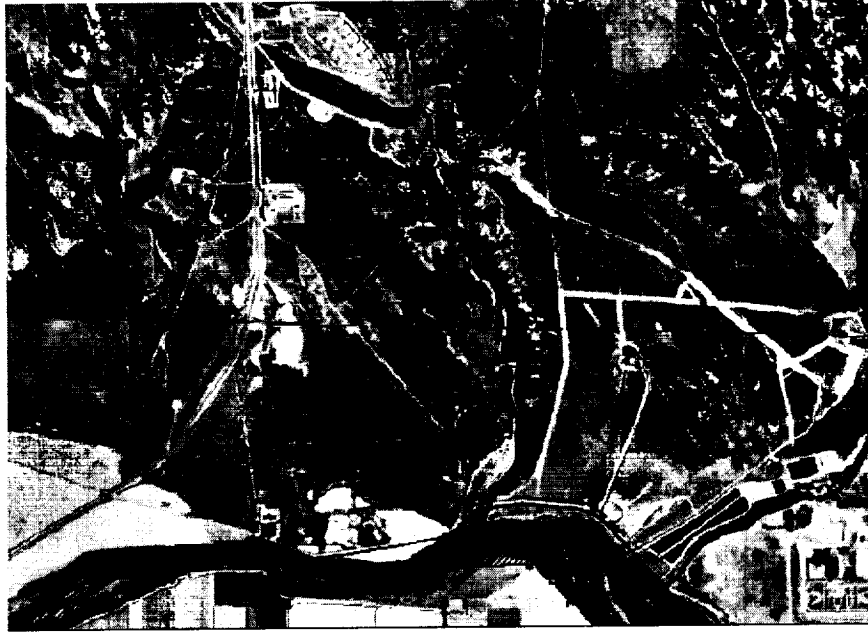


Figure 26: Aerial Photo, Streams, Roads, and Buildings. All vector layers supplied by VAFB for study



Figure 27: Point count locations on land cover map

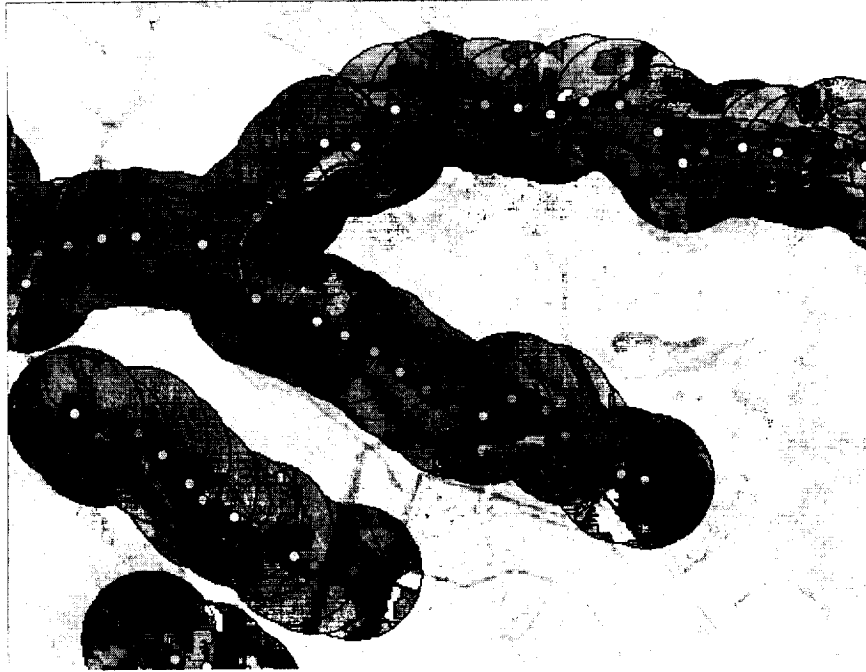


Figure 28: Buffer and analysis of land cover within a radius of point count survey

4. Grant Performance Metrics

ISRG/GSRU has had the overall goal to demonstrate to the broad user community the operational and commercial potential inherent in the latest OES satellite remote sensing data and information products. As an academic research group, ISRG research performance has always been measured, at least in part, by academic metrics of awarded degrees, published refereed journal articles, and professional symposia presentations. These metrics are again useful for measuring performance during this reporting period. But, as this is the concluding year in a long-term research program, other performance metrics used in previous years (web site hits, data set distribution) are less useful because part of the process of project closure includes moving data sets to alternate hosts and sponsoring groups and transferring data sets to collaborating researchers.

Three specific performance metrics were used this year:

1. *Publications:*

Goal: A minimum of 3 Papers per year published in reviewed journals and proceedings.

Performance: During this funded year ISRG/RSRU researcher published 7 articles in reviewed journals; and 8 proceedings papers/abstracts/presentations

2. *Academic:*

Goal: 1 Master and/or Doctoral Degree granted.

Performance: 4 research interns working under NAG5-10457 received Undergraduate degrees, 2 Master of Arts and one PhD degrees were awarded to RSRU graduate student researchers.

3. *Symposia:*

Goal: Maintenance of a high level of presentation of grant related material at professional meetings.

Performance: During this reporting period ISRG/RSRU researchers made 16 presentations at professional meetings both nationally and internationally. These included presentations at the Annual International Geoscience and Remote Sensing Society (IGARSS) meeting in Sydney, Australia, July 2001, the Association of American Geographers (AAG) meetings in Los Angeles, CA during March, 2002, and at the International Steering Committee for Global Mapping (ISCGM), in Budapest, Hungary, in September, 2002.

From an analysis of this material we believe we met or exceeded the performance goals which were used during the reporting period.

5. Summary

This document represents the final technical report for National Aeronautics and Space Administration (NASA) Office of Earth Science grant NAG5-10457, titled "Remote Sensing Information Science Research Group". This grant supported research performed by the Information Sciences Research Group of the Remote Sensing Research Unit (ISRG/RSRU) at the University of California, Santa Barbara (UCSB). NAG5-10457 is the final research grant in a long-term program of NASA sponsored research by ISRG. The period of performance for this grant was 1 March 2001 through 30 September 2002.

Following directly upon past research, the fundamental research objectives of this NASA grant were to:

- Improve understanding of public sector operational and commercial applications potential of Earth Science Enterprise (ESE) satellite remote sensing data and information.
- Provide outreach to inform the Earth science remote sensing user community, environmental planners, resource managers, educators, public policy decision-makers and the general public of the basic and applied research and public sector and commercial potential of advance satellite remote sensor systems.
- Facilitate the implementation of a broad-based remote sensing applications research program to the benefit of the applications user communities and the public at large, via research, education and outreach.

ISRG/RSRU research will help to forward the transition of Earth Science results to the broad remote sensing applications user community. This research was also aimed to address issues related to operational applications. Such applications include global framework data and land cover mapping, biodiversity, and expanded applications and commercial potential of Earth Observing System data. Through presentations and discussions at national and international level, RSRU research was extended to the user community to inform them of the potentials offered by ESE data and information products. Finally, ISRG/RSRU research continues to have the goal of demonstrating to the broad user community the operational and commercial potential inherent in the latest OES international and commercial satellite remote sensing data and information products.

This document presents a survey of research proposed and performed within RSRU and the UCSB Geography Department during the past 25 years along with a summary of research topics addressed under this grant during the reporting period:

- NASA ESA Research Grant Performance Metrics Reporting
- Global Data Set Thematic Accuracy Analysis
- ISCGM/Global Map Project Support
- Cooperative International Activities
- User Model Study of Global Environmental Data Sets
- Global Spatial Data Infrastructure
- CIESIN Collaboration
- On the Value of Coordinating Landsat Operations

- The California Marine Protected Areas Database: Compilation and Accuracy Issues
- Assessing Landslide Hazard Over a 130-Year Period for La Conchita, California
- Remote Sensing and Spatial Metrics for Applied Urban Area Analysis, including
 1. IKONOS Data Processing for Urban Analysis
 2. Image Segmentation and Object Oriented Classification
 3. Spectral Properties of Urban Materials
 4. Spatial Scale in Urban Mapping
 5. Variable Scale Spatial and Temporal Urban Growth Signatures
 6. Interpretation and Verification of SLEUTH Modeling Results
 7. Spatial Land Cover Pattern Analysis for Representing Urban Land Use and Socioeconomic Structures
- Colorado River Flood Plain Remote Sensing Study Support
- African Rainfall Modeling and Assessment
- Remote Sensing and GIS Integration

Specific metric goals for this year's research were:

1. A minimum of 3 Papers per year published in reviewed journals and proceedings
2. 1 Masters and/or Doctoral Degree granted
3. Maintenance of our already high level of presentation of grant related material at professional meetings.

Results achieved in meeting these goals are as follows:

1. During this funded year ISRG/RSRU researcher published 7 articles in reviewed journals; and 8 proceedings papers/abstracts/presentations
2. 4 research interns working under NAG5-10457 received Undergraduate degrees, 2 Master of Arts and one PhD degrees were awarded to RSRU graduate student researchers.
3. During this reporting period ISRG/RSRU researchers made 16 presentations at professional meetings both nationally and internationally. These included presentations at the Annual International Geoscience and Remote Sensing Society (IGARSS) meeting in Sydney, Australia, July 2001, the Association of American Geographers (AAG) meetings in Los Angeles, CA during March, 2002, and at the International Steering Committee for Global Mapping (ISCGM), in Budapest, Hungary, in September, 2002.

An increasing world population continues to put pressure on our global resource base. This increased pressure requires improved understanding of the factors that influence change in the Earth system. It also requires that new and improved ways be developed to employ remotely sensed data to promote economic growth within the context of sustainable economic development and more livable communities. Research in both of these areas must not only be focused on specifics and processes but on increasing both fundamental and applied understanding. The ISRG/RSRU research program has aided earth system scientists, commercial vendors, entrepreneurs, environmental planners, resource managers, and public policy makers at scales from local to global to appreciate and realize the potential of remotely sensed data. Expanding the range of applications of remote sensing will help to advance the development of geospatial information and enhance the availability of this information and technology for the benefit of future generations.

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7. Appendix I. Selected RSRU Publications during Reporting Period

Global Mapping and National Mapping Organizations at the Turn of the Millennium: The Challenge of a Changing World

John E. Estes

Anderson Revisited: A Twenty-five Year Perspective

Loveland, Thomas, Joseph Scepan, and Larry Tinney

Remote Sensing and Landscape Metrics to Describe Structures and Changes in Urban Land Use

M. Herold, J. Scepan, and K. C. Clarke

Object-oriented Mapping and Analysis of Urban Land Use/Cover Using IKONOS Data

M. Herold, J. Scepan, Andre Muller and Sylvia Gunter

A Multi-temporal Framework for Mapping and Analysis of the Spatial and Temporal Pattern of Urban Growth

M. Herold, Keith C. Clarke and Gunter Menz

International Environmental Agreements and Remote Sensing Technologies

Karen Kline and Kal Raustiala

An Overview of the Global Map Project

Karen D. Kline and John E. Estes