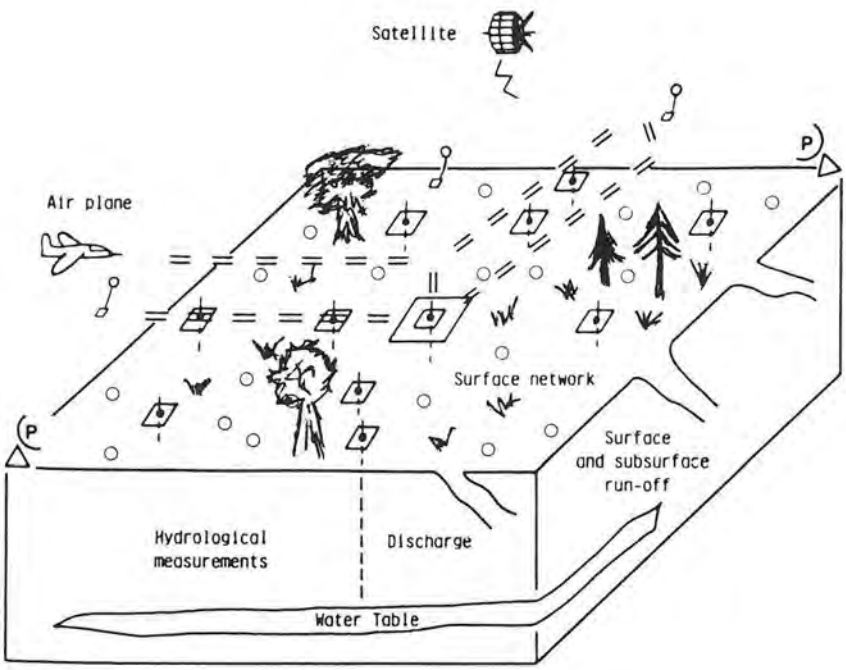
GLOBAL CHANGE

IGBP

REPORT No. 8



Pilot Studies for Remote Sensing and Data Management

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)

GLOBAL CHANGE
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Pilot Studies for Remote Sensing and Data Management

Report of a Meeting of the IGBP Working Group on Data and Information Systems

at WMO and UNEP's GRID Facility
Geneva, Switzerland
11-13 January, 1989

Edited by S. I. Rasool and D. S. Ojima
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The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)

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TABLE OF CONTENTS

EXECUTIVE SUMMARY 1

1 PURPOSE 3
- 1.1 Design a Pilot Data Project 3
- 1.2 Satellite-Derived Vegetation Index 3
- 1.3 Assessment of the End-to-End Performance 3
- 1.4 Data Directories 3

2 LAND-COVER CHANGE PILOT STUDY 5
- 2.1 Introduction 5
- 2.2 Objective 7
- 2.3 Products 7
- 2.4 Approach 8
- 2.4.1 Clarification of user needs 9
- 2.4.2 Land cover classification 9
- 2.4.3 Remote sensing requirements 10
- 2.4.4 Ancillary data inputs 11
- 2.4.5 Site selection criteria 11
- 2.5 Research and Data Management Tasks 13
- 2.6 Candidate Regions 15
- 2.7 Action 18

3 GLOBAL CHANGE DISKETTE PROJECT 21
- 3.1 Introduction 21
- 3.2 Objectives 21
- 3.3 Goals 21
- 3.4 Examples of Interesting Generic Questions 22
- 3.5 Examples of Regional Problems of Importance to IGBP 22
- 3.6 Design Desiderata, Initial Phase 22
- 3.7 Proposed Project Design 23
- 3.8 Schedule 24
- 3.9 Other Aspects 25

4 END-TO-END SYSTEMS STUDY ON SURFACE TEMPERATURE DATA SET 27
- 4.1 Introduction 27
- 4.2 Towards Planning of an End-to-End Test on Surface Temperature Data Sets 27
- 4.3 Land Surface Temperature from Satellites 27
- 4.4 Action 28

5 IGBP DATA DIRECTORIES 29
- 5.1 Data Directories 29
- 5.2 Action 29

6 REFERENCES 31

APPENDICES 33
- Appendix A Participants 35
- Appendix B Glossary 39
- Appendix C Acronyms 41

LIST OF FIGURES AND TABLES

Figure 1 Central Role of Land Cover Determination to IGBP Global Change Studies. 6

Figure 2 Candidate Regions for the IGBP Land Cover Change Pilot Study 16

Table 1 General Ranking of Potential Pilot Site Areas 16

Table 2 Time Table for Pilot Study on Land Cover Change 19

EXECUTIVE SUMMARY

The SC-IGBP Working Group on Data and Information Systems met in mid-January 1989 at WMO and UNEP-GRID, Geneva, Switzerland, with many invited experts, to discuss several early data projects for the Global Change Programme, and propose details of their objectives, plans, participation and possible implementations. These details comprise this report.

The Working Group and experts identified one project that would establish several baseline observing sites for documenting and studying change induced by human activities and three projects dealing with existing data that are highly useful to studies and documentation of Global Change.

The first project, the Land-Cover Change Pilot Study, proposes regional pilot projects to establish globally-applicable methodologies to measure large scale changes in land cover. The proposed strategy is to select several sites of different climate and land-cover characteristics on which extensive multi-satellite imagery will be gathered to document existing conditions and changes occurring in the past decade. Initial classification scheme for land cover will be relatively coarse and robust so that it can be consistently implemented at all sites. Observations would include survey-type satellite data (e.g., 1-km AVHRR) validated against a limited number of samples of higher-resolution data from LANDSAT and SPOT as well as with samples of aerial photography and in-situ observations. The aim is to estimate the unbiased fraction of each category of land cover even when land-use information varies within a pixel. This can probably be done by using time history as well as spectral data and regional knowledge of the ecosystems. It is proposed that sites be well instrumented, that local as well as international teams work there, and that observations be carried out for a number of years. It is possible that some of these sites might be chosen for locating IGBP Geosphere-Biosphere Observatories.

The second project, the Vegetation Imagery Diskette Pilot Project, involves preparation of global data sets of variables useful to study changes resulting from climatic variability as well as from human activities. A basic data set of wide interest and use for study of change is vegetation imagery derived from operational satellite observations in several spectral bands. Such derived products are called Vegetation Index (VI), although it is not known yet exactly what vegetation characteristics are reflected in the empirical "index." As a first phase, VI data of the continent of Africa in four-week blocks for a four-year period will be condensed onto four 5-1/4 inch floppy diskettes that can be read and manipulated by personal computers ranging from IBM XT to PS2 types. Display and manipulation software that also includes raster-type geographical indexing will be supplied, as well as several ancillary climatic or land-cover or land-surface data sets. With the cooperation of UNEP and UNITAR, workshops will be arranged for training research groups in Africa in using these data sets to conduct local research projects. Ultimately, continents will be included and finally global data sets will be produced on CD-ROMs.

The third project is to develop methodologies for testing the consistencies of important data sets that are derived from both satellite observations, from which global climate trends can

be determined. One candidate variable is surface temperature. The World Meteorological Organization (WMO) will collaborate with the IGBP and the WDC-A (oceanography) to design an end-to-end test on surface temperature data sets now being used to derive trends in global change. A parallel activity to evaluate the satellite techniques for observing land surface temperatures will be initiated. In collaboration with ISLSCP, the IGBP will organize an algorithm intercomparison programme which should result in identifying the deficiencies. The project is planned to be part of the Global Information System Test for the International Space Year in 1992.

The fourth project deals with developing methodologies for developing a universal Global Change Data Inventory in which global and large-scale data sets for studies of global change useful for global-change studies would be readily found and researchers would find out where and under what conditions to obtain the data sets.

1 PURPOSE

The Moscow Study Conference on IGBP Data and Information Systems, August 9-13, 1988, and the Stockholm Scientific Advisory Council meetings, October 24-28, 1988, identified several priority areas which need to be addressed by our WG. These areas are:

1.1 Design a Pilot Data Project

Design a pilot data project, including an assessment of the quality of the end product. An excellent candidate will be a project on land cover change to study a stratified sampling strategy using both satellite data and ground based observations for consistency and validation. This design should provide a baseline from which changes can be measured and the project can then be extended to cover the entire land surface area of the Earth.

1.2 Satellite-Derived Vegetation Index

A satellite-derived vegetation index is operationally available at medium resolution for the entire earth surface. A strong worldwide programme of field experiments and theoretical studies to assist in interpretation is under way. A pilot programme for data distribution of vegetation index data on diskettes to about 100 researchers around the world has been proposed by the ICSU - World Data Centers.

1.3 An Assessment of the End-to-End Performance

An assessment of the end-to-end performance of existing observations and data systems for long-term measurements for at least one global variable important to the IGBP. Ffor global change studies, we need data of long-term stability and coherence in techniques with certitude on the magnitude and direction of the change. There is no assurance that present data collection efforts are adequate for this purpose. It is proposed to take surface temperature, especially land-surface temperature, as the variable to be examined and analyzed using surface-station data as well as surface temperatures derived from satellite radiance observations.

1.4 Data Directories

In order to begin some global change studies now, before the new IGBP observational programs get implemented, we need to use existing data. While some major data sets are generally available, the locations of many other existing data sets are not widely known. There are some efforts in several countries to locate and describe such data sets, and to assess as appropriate their quality and applicability to global change studies. Under IGBP auspice, we must build on these efforts to organize internationally, in collaboration with appropriate other organizations, directory of major existing data banks relevant to IGBP objectives, indexed by subject.

A three-day meeting of an ad-hoc group of about 20 specialists (see Appendix A) was organized in Geneva at the WMO, in collaboration with the grid facility of UNEP to go over

in detail plans for a land cover change pilot study, its experimental design, site selection criteria, candidate sites and schedule.

Discussions were also held on a data set distribution project as proposed by the World Data Center and a draft plan of action was proposed. Recommendations related to the end-to-end system test for available data sets on surface temperature and on ways to build directory of existing data banks relevant to IGBP are also included in this report.

2 LAND-COVER CHANGE PILOT STUDY

2.1 Introduction

The IGBP has set before itself a tremendous task in the investigation of "global change". The Programme objective is:

> "To describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions." (IGBP Report 1, 1986.)

The IGBP must achieve a basic level of understanding of the intricate interactions among the Earth system components to have any probability of attaining its objective. The following set of underlying themes form the fundamental basis of the research projects of the IGBP (See IGBP Report 4, 1988, for more detail):

* documenting and predicting global change,
* observing and improving our understanding of dominant forcing functions,
* improving our understanding of transient phenomenon, and
* assessing the effects of global change that would cause large-scale and important modifications affecting the availability of renewable and non-renewable resources.

A primary goal of the Programme is therefore to advance our ability to document and predict changes in the global system. Our ability to discern land cover globally is fundamental to achieving this goal. Remote sensing is the only feasible method of accomplishing a consistent and uniform coverage of the Earth's surface. The spatial and temporal resolution of this coverage is adequate for documenting general land surface characteristics.

The IGBP is composed of multi-disciplinary set of collaborating disciplines, spanning from atmospheric chemistry to microbiological studies, from past Earth history studies to future predictions of the Earth's environment, and from the depths of the ocean, to the surface of the land, and to the upper reaches of the troposphere. As a start, the initial emphases in the IGBP will be to obtain the information necessary to understand more completely the cycling of water and key elements among ecosystems, taking into consideration the natural and anthropogenic factors affecting these cycles, and the interactive effects of climate-induced feedbacks within and between the biosphere and the atmosphere. Characteristics of the land surface, i.e., land cover, in many ways reflects the cycles of these critical elements. Information relating flux rates of key biogeochemical elements to land-cover types will be essential to extrapolating from process level studies in a localized area to global estimates contributing to global changes in various components of the Earth.

2.4 Approach

There is now a critical need in several areas of global change research to develop a land cover and land use dataset. This has been, in part, the outcome of the increased awareness of the importance of developing geographically detailed land process models (see for instance Bolin, 1984). Among others, initiatives in modeling global biogeochemical cycles, climate modelling, biosphere-atmosphere interaction studies, and analyses of climate change on terrestrial ecosystems all require the development of geographically detailed datasets which systematically provide a description of the state of the land surface.

Datasets, which describe such state variables globally, provide a framework upon which process models can be parameterized and scaled. They include basic information on vegetation, soil, topography and other features. From these biophysical descriptions, parametric datasets of more quantitative measures can be derived, such as organic matter content, net primary production, or soil moisture. These parametric data, in turn, are vital elements in the formulation of a dynamical characterization of climate and nutrient, water, and energy flux.

Yet, basic information on land cover, land use, soil cover, topography and other features is not presently available with sufficient geographical detail or thematic and temporal consistency to support global change models. Clearly, the development of such data is an important first step in a programme of global change; the difficult issue is one of developing an approach. The development of a Land Cover Pilot Study would provide insights into an approach.

Conceivably, a land cover dataset could be developed in two ways: 1) in a cartographic fashion as the result of combining maps of land cover and land cover change, including information on other aspects of the physical environment (e.g. soils), 2) by utilizing a suite of remotely sensed data over a range of temporal, spectral and spatial scales. A combination of both approaches, complemented with a set of strategically placed in-situ measurements and studies, is likely to be the best.

Both remote sensing/image processing and geographic information systems technologies will play a critical role in the development of a land cover test of this kind. The various data formats and data sources dictate that new methodologies be employed in global change studies which are capable of linking the raster format of remotely sensed data, the point or tabular format of in-situ data, the vector format of cartographic data, and the grid format of models.

In addition to providing a means toward the encoding of these data formats, an integrated geographic information system provides the means to geoposition multiple datasets (e.g. rectification, georeferencing, co-registration), integrate data across various resolutions and scales, process data (e.g., contouring, extrapolating, layering, correlating), manage and catalog datasets, and display data.

A number of steps will have to be taken to insure that this study succeeds. These steps include:

* clarification of end-user needs;

* classification scheme for land cover;
* acquisition of appropriate remote-sensing data relative to spatial and temporal scaling, spectral frequencies, and class of imagery we use;
* ancillary data needed (e.g. soil, weather, land use, etc); and
* site-selection criteria;

2.4.1 Clarification of User Needs

Observational parameters and information extraction algorithms will also have to be developed for quantities such as primary production and trace-gas emissions for use global modelling, document changes in land cover, input into land use database, meaningful to global-change related process studies in extrapolation to global scale.

2.4.2 Land Cover Classification

The classification should consist of coarse categories of land cover such as: evergreen forest, deciduous forest, shrub, grassland, desert, snow and ice, arable, wetland, urban. It will be important to define a land-cover classification suitable for the pilot project and which addresses central issues relative to IGBP research objectives. Land-cover categories can be further subdivided at a later stage in a hierarchical fashion in terms of a more detailed description of natural vegetation or land management. The classification provides a basis for selecting representative regions, as well as a framework for mapping, methods development and calibration. The pilot sites selected should collectively represent an ensemble of land-cover categories in the classification adopted for the study.

There are many land-cover and land-use classifications in existence. Examples include the Unesco system includes many categories, but is primarily a depiction of natural ecosystems. The World Atlas of Agriculture, prepared under the aegis of the International Association of Agricultural Economists in 1969 by the Instituto Geografico De Agostini in Novara, Italy, contains maps at 1:2.5M scale for West and Central Europe, the Middle East, North America, Japan and New Zealand; and maps at 1:5M scale for USSR, Asia, Australia, Africa and Latin America. The emphasis is on land utilization and relief. The USSR land-use map developed at 1:15 million scale by the Soviet Institute of Geography (1986) which delineates approximately 80 categories of natural and managed units, many being multiple combinations.

For the IGBP, a hierarchical system of classification which would define land cover in terms of both natural and managed types should be developed. This system should be generally applicable and should consist of categories which can be derived from satellite classification techniques. The hierarchical structure would permit multiple satellite-sensor resolutions to be used, from a general land-cover scheme for AVHRR to a detailed scheme for land cover and possibly land use with high spatial resolution imagery such as SPOT/LANDSAT or ground data derived from other international organizations (e.g. ISSS). This hierarchical classification would permit these various sensor resolutions to be utilized for scaling-up or collapsing finer-resolution information to coarser-resolution information to be put into the final map or data base. This final classification scheme should be devised by a small ad-hoc group of the IGBP and UNEP (GEMS).

For some purposes, land cover is considered static (i.e., to the extent that it represents natural systems in the absence of human disturbance). In such case, a single snap-shot depiction of land cover should suffice. However, in the context of global-change issues even natural systems are dynamic. For instance, changes in fire frequency or in climatic regimes directly influence changes in land cover, if even in very subtle ways. Consideration must be given to these subtle changes, and to changes due to human activities.

In terms of land-cover change, three priority areas can be defined:

Type 1: areas undergoing rapid change from one cover to another;

Type 2: areas sensitive to change due to natural or anthropogenic pressures;

Type 3: areas that have a significant influence on our global environment or on global change.

2.4.3 Remote-Sensing Requirements

Land-cover mapping and data-base development should be capable of providing compound mapping units with sub-pixel inventories of fractions or percentages of various land-cover types. This is achieved by compiling data at finer resolutions than the final product. Geographical scales will reflect the sensor systems utilized, predominantly AVHRR for global coverage. Time scales to be considered will be both long-term forward monitoring (up to 10 years after a 2-3 year inventory period), and back tracking for atleast a decade. Consideration must be given to financial resources (especially for ground truth), minimum study area size for correlation studies between different sensors utilized and in-situ data, and availability of existing data for a site.

In selected pilot areas, AVHRR satellite data in full resolution (HRPT) mode should be used, cross-checked with sample high-resolution SPOT and/or LANDSAT scenes, and validated against aerial photography and in-situ data. Satellite remote sensing provides the only feasible, globally consistent coverage, but is subject to potential ambiguities in interpretation. The challenge is to establish a stable, long-term classification that is sufficiently accurate to detect relatively small changes in land cover, and well validated against in-situ data in a variety of climatic and vegetation regimes. AVHRR 1-km data provide economical daily coverage, allowing good large-scale documentation of the annual cycle but with relatively poor spatial resolution; this should suffice for most purposes. Higher resolution is only needed sporadically for validation.

Frequent coverage is essential to increase the probability of acquiring global cloud-free image coverage over a short period during which land surface conditions remain relatively constant. In-situ observations are difficult to organize and very expensive, so high-resolution remote sensing such as SPOT, LANDSAT and aerial photography is required as an intermediate step in the validation process. A well designed stratified sampling scheme will be essential to obtain detailed information on land cover composition within the larger 1-km pixels and to statistically assess the accuracy of the resulting map products.

Since a thoroughly tested algorithm using AVHRR data is not available, it will have to be developed during the pilot program. Data used for this development must be rigorously

separated from that intended for validation. Satellite data collected over one full year might be sufficient to complete a land-cover map, but it will be necessary to verify the algorithms for two or more years to allow for inter-annual variability in climate parameters such as precipitation, and the phenological cycle. It may also be necessary to make special analyses to identify major disturbances such as fire or flood. Topography and, in semi-arid climates, variations in soil properties will have to be taken into account in interpreting spatial patterns and in the design of stratified sampling.

2.4.4 Ancillary Data Inputs

Datasets needed to help interpret remote sensing data include type of vegetation, soil charactersitics, topography and other features which help describe the land surface. Additional information on land use (as opposed to land cover) could include information on road networks, ownership patterns, local agricultural practices and crop-sequencing models. These data will be helpful in resolving ambiguities on fine spatial scales and in phenological structure as well as to serve as the basis for assessing future changes in land cover.
Back tracking of land cover is a useful tool in validating current methods of estimating land cover. Where data exist, estimates of changes in land cover over the past 15 years using similar techniques will allow a more detailed test of the sensitivity of the techniques to detect changes in land cover over a broader range of geographic distribution and weather conditions. Availability of suitable data may be a serious issue here.

2.4.5 Site-Selection Criteria

A set of criteria must be established to select pilot-study areas. The criteria should be developed on methodological, scientific and logistical grounds. Pilot-study sites (probably 2 or 3) will be chosen based on how well they fit the criteria below. It is to be hoped that sites could be chosen which satisfy all of the criteria listed; in that sense the criteria act as filters.

The criteria are:

1. Rate and characteristics of change. Areas in which land-cover change is occurring will receive high priority for consideration. Change can be considered in several ways. First, there are regions in which there is a large magnitude of change, but the rate of change may or may not be increasing (the linear case). Second, there are regions in which the magnitude might or might not be high, but the rate of change is increasing (the non-linear case). The rate of land-cover change in a region might be subtle or rapid, either can be potentially important depending on the area. Third, there should be a consideration of areas in which the change in land cover is slow, but its effect is magnified by special characteristics of the landscape, such as pockets of high biomass (e.g. wetlands), highly fragile environments, or ecologically unique habitats. The ability to monitor these changes will be an important test of the developed methodology and indicate the scale necessary to discern global changes of the land surface.

2. Spatial characteristics. The spatial characteristics (i.e. landscape patterns) of a site should reflect both the unique cases (e.g. areas of marked deforestation or desertification) likely to be present in a global appraisal as well as the typical cases. Here consideration will be given to information extraction factors. Emphasis should be placed on areas with land-cover heterogeneity (e.g. areas with a variety of land cover types or land uses) at scales below the AVHRR resolution level of 1 km, but with enough uniformity to make sampling and scaling tests possible.

3. Latitudinal Distribution and Biome Distribution. The collection of final study sites should constitute a geographically and/or ecologically representative sample. Emphasis is placed on tropical, subtropical arid and semi-arid, temperate, and boreal regions.

4. Relevance to Global Processes. The development of a land-cover data set should be carried out in the context of its relevance to basic IGBP science initiatives, such as biogeochemical cycles and water-and energy-balance analyses. The sites should be indicative of regions where land cover and land-cover changes have the potential to influence these global processes, even if the change itself is local or regional. The areas should be suitable for modelling studies in conjunction with the land-cover mapping and basic data collection pilot efforts. Such modelling efforts would focus on the influence of land-cover changes on atmospheric and climatic process (e.g. water flux, carbon dioxide flux, trace-gas emissions, surface roughness, and albedo) and the influence of climatic and atmospheric changes on land-cover change (e.g., temperature and precipitation effects, wet and dry-deposition effects).

5. The Availability of Data. Since a plethora of co-registered data sets will be required, there should be a high probability of obtaining them in the areas selected. Data required include satellite data (AVHRR HRPT, Landsat-MSS, TM, SPOT), maps, ancillary tabular data sets, and long-term land-use records. This requirement also implies the ability to orchestrate synchronized field reconnaissance and verification efforts in the areas selected.

6. Existence of Ecotones or Transition Gradients. Gradients of land cover are significant and dynamic areas (di Castri et all 1988). Human activities along transitions often have profound effects on land processes, and they (e.g., biomass burning) often cluster along transition areas. Many transition areas are fragile areas, which are quickly degraded when perturbed (i.e., small changes can have large impacts). Areas selected should therefore include these gradients. The gradient should be defined ecologically, but might be influenced by gradients in the physical environment.

7. Soil and Terrain Characteristics. Although of secondary importance to the study, soils and terrain features (e.g., topography) will be utilized to improve the discrimination of land-cover types. Emphasis will be given to areas with well documented soil conditions (e.g., accurate soil mapping and classification), areas with known fragility or degradation hazard, and areas with sufficient variations in soil conditions.

8. Scientific Environment and Co-lateral Studies. Preference should be placed on areas in which there now or will soon exist other scientific activities. This includes activities being sponsored from within or outside of host countries, but ideal sites must have active host-country efforts.

   Also of importance is the existence and involvement of "ground truth" institutions with the ability to provide technical and logistical support.

9. Available resources to support the study.

2.5 Research and Data Management Tasks

A number of tasks related to data management and data processing must be considered in the development of the pilot project. Documentation of these procedures and criteria for data handling and processing will serve as a guide in the development of the methodology used in this pilot study. These tasks include:

* Acquire daily AVHRR daytime 1-km digital data from local HRPT line-of-sight receivers. The acquisition of data from morning and afternoon passes is highly desirable. Reliability and continual operation is essential during the study.

* Convert radiances to reflectances, correcting for instrument drift, solar-zenith angle, Rayleigh scattering, and possibly Mie scattering land water vapor absorption using climatological values of humidity. A special programme will be needed to determine instrument calibration drift.

* Precisely register and interpolate to 1-km mapping grid with a sub-pixel accuracy. Suitable navigation-landmark ground-control points must be defined and located.

* Prepare cloud-free composite images for each pixel into time sequences over 4 to 6-week periods each during the 1-year period. The selection of several characteristic time windows over the 1-year period will result in a basic data set consisting in a space of 5 spectral X (perhaps) 6 temporal dimensions. The original data should be preserved in the form received to permit experimentation with this compositing process.

* Identify clusters of data points in the spectral-temporal space which, correspond to a single pure class of land cover, and then classify all remaining pixels as a linear combinations of such pure classes, i.e., identify the fractional area within the pixel that falls in each class. The ability to discriminate pure classes will depend critically upon the phenology of the vegetation as revealed in the time-sequence composite, and the extent to which they are revealed as extrema in the multi-dimensional space of data points. How reliably and accurately this can be done is a major research question for this pilot project. Also unclear is the extent to which data on soil type and topography (a surrogate for precipitation-variability) are necessary to stratify groups of pixels prior to classification.

* Acquire a pre-planned sample of SPOT and/or LANDSAT scenes based on a stratified random sampling design, and perform a high-resolution analysis of selected areas along similar lines. This sample should be designed statistically to verify that

the pure classes identified by AVHRR are indeed pure, and that the fractional area for mixed pixels is being correctly estimated. The available sample of such high resolution data should be larger than required solely for verification purposes, because some iteration in the development of the classification procedure is likely to be needed.

* Conduct on-site surveys for selected pixels of the mapping grid, for selected high resolution pixels. On-site work should be supplemented by aerial photography. Compare results with those obtained from satellite data.

* Assemble local data on land use, and relate these to measured patterns of land cover. Develop a relatively simple hierarchical system of land-use types at the global level, in which the local information on land use can be accommodated.

* Disseminate results and data bases to the international scientific community.

* Repeat the analysis of AVHRR data for at least one more year to ascertain if the land-cover pattern remains constant in spite of weather effects on vegetation or develop a better understanding of how vegetation varies with the different weather conditions. The analysis of high-resolution satellite data as well as the collection of ground data need not be repeated. Compile results and distribute the updated database.

2.6 Pilot Areas

Below we list 10 areas which generally fulfill the aforementioned criteria (Section 2.4.5). We list them with a brief overview of why they were chosen and their particular significance. Table 1 shows a generalized rating of each area by the aforementioned criteria and Figure 2 shows their approximate location on a world map.

1. Tropical rainforest. The tropical rainforest of Brazil is an example of a region where land-cover changes are occurring at rapid rates (deforestation rates in 1987 are estimated at 8 million hectares, and total land-cover conversions including grasslands and shrublands as high as 20 million hectares Setzer 1988). Changes are especially acute in the high biomass areas of the Amazon Basin, and in the forest-woodland/shrubland transition zones bordering the Amazon Basin.

   While the Amazon region and neighboring regions offer interesting possibilities for monitoring and mapping important land cover and land-cover change regions, the Northeast of Brazil is a dry zone in which there has been considerable abandonment, regrowth, and land degradation, but few efforts to document these processes. There now exists a number of on-going research efforts involving the use of remote sensing, GIS, and modelling which provides a good international cross-section of research. There also exists considerable Brazilian expertise and capabilities. The Space Research Institute of Brazil (INPE), the Brazilian Academy of Sciences and other institutions in Brazil are directly involved in remote sensing of environmental and global climatology. Experiments are being developed in situ to study the Amazon Basin water balance.

2. Tropical savanna. West Africa represents a promising area where there now exists considerable international, on-going studies, and multi-disciplinary work. Against an ecological backdrop of an environment highly seasonal in nature (with respect to net primary production (NPP)), human activities are drastically and rapidly influencing land-cover change. A combination of cash cropping, changing patterns of nomadism and shifting cultivation, and rising population pressures on the regional landscape offer interesting contrasts to other areas (cf. the Amazon). Recent studies also show that areas of natural vegetation are greatly influenced by external climatic forcing agents, such as ENSO. West Africa offers a variety of land cover types and environments, ranging from savanna to forest. Land-cover change in the forests has been observed remotely, and it offers an interesting comparison to other regions, such as in Brazil. Remotely-sensed data exist at a variety of scales as do ancillary data sets.

3. The Prairie-Boreal Region. The Prairie-Boreal region of Canada offers a steep ecological/land cover gradient outside of the tropics, from semi-arid grasslands through boreal forest to the tundra of the North. Numerous research activities are taking place in the region, and historical land-occupation data are available for the period of settlement. There are few manpower, logistical, and technical limitations. The land cover is presently relatively stable, although some changes are occurring due to conversion from, and to, agriculture. In terms of global change processes, this area offers a promising mid-to high-latitude region for monitoring land-cover changes resulting from the predicted dramatic changes in temperature and precipitation patterns. The boreal forest and wetlands play an important role in the global carbon

Table 1. General Ranking of Potential Pilot Areas.

SITES / CRITERIA	Brazil	West Africa	Prairie Boreal	China	USSR Boreal	Spain (Arid)	Central U.S.	Austr alia	S. E. Asia	N. E. Africa
Rates of change	H	H	L	L	L	M	L	H	L	H
Spatial characteristics	H	H	M	H	L	M	L	L	L	M
Distribution	H	H	H	H	H	H	H	H	H	H
Relevance to Global Change	H	H	H	H	H	H	H	H	H	H
Data avail.	H	H	H	?	?	?	H	H	?	H
Gradients	H	H	H	H	L	L	H	H	L	H
Soil and Terrain	H	H	H	?	?	?	H	H	?	?
Institutional Support	H	H	H	?	H	H	H	H	?	H
Resource avail	H	H	H	?	?	H	H	H	?	H

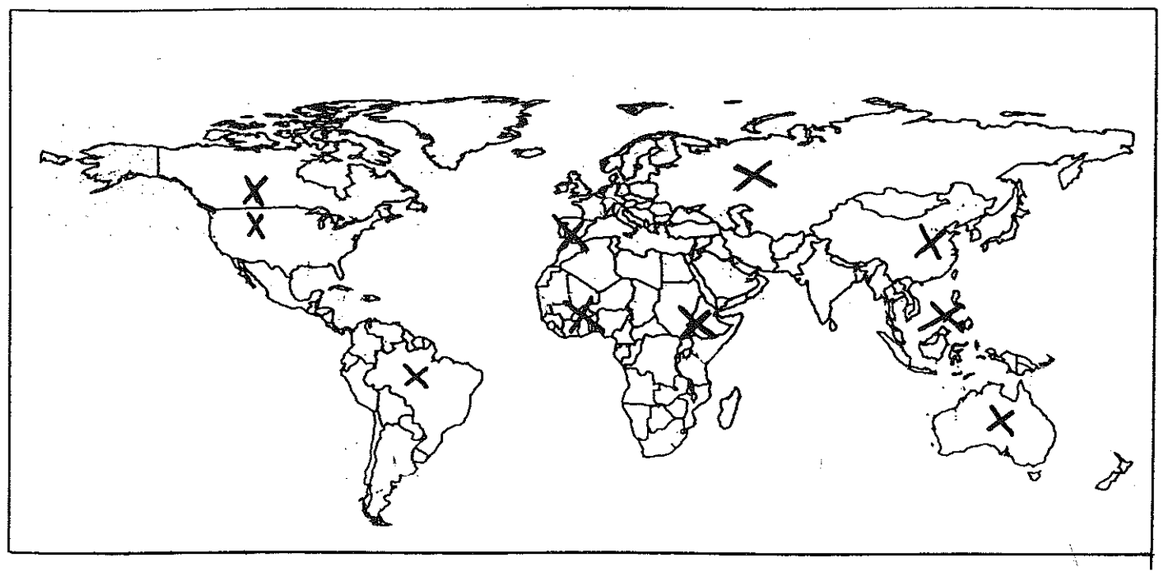

Figure 2. Candidate Pilot Areas for the IGBP Land Cover Pilot Study.

storage and methane production. The entire area has been relatively undisturbed until the last century thus, offering an opportunity to isolate natural and anthropogenic agents of change. gradients and precipitation.

4. China. Yellow River Arch area (Shensi-Ningsia Hui and part of Inner Mongolia). This area is of temperate continental climate and has a subhumid loess plateau in the southern half with denudational features, agricultural land use changes, semi-arid steppe land north of it and bands of riverain/ancient deltaic wetlands and irrigated lands. It also has ecotonal situations, with many records of past climatic change. Several research institutions of the Academia Sinica are potentially interested. Satellite information from own platforms are available through the Chinese WDC.

5. Boreal Forests of USSR. This region offers promise for testing methodologies in almost completely undisturbed regions. It is believed to be an important place to test the sensitivity of the methodologies when land cover is unchanging and homogeneous. This is not to underestimate its role in global change, especially in the context of such factors as carbon storage and possibly also as a key region to monitor for biospheric changes resulting from climatic changes.

6. Southern Spain. This area represents an opportunity to study an arid region potentially with considerable institutional support and data availability derived from the planned ISLSCP study to be conducted in the early 1990's. Rates of change are relatively low, but there is potential for land degradation from minor changes. The low rates of change in a low biomass/NPP area offer opportunities for sensitivity testing of methodologies.

7. Midwest United States. This is a region of low recent land-cover transition, and relatively uniform spatial characteristics. It offers an interesting examination of shifting patterns of irrigation and of drought-condition effects on land cover characteristics. There is an excellent existing remote-sensing programme with considerable institutional support. Past, current, and future data availability is very high at all levels. It is an area with one of the best possibilities to develop a final product.

8. Australia, New South Wales. In this region of the Southern Hemisphere, a steep gradient of land cover exists. Soil degradation features are also abundant (Soil Conservation Service of NSW). Considerable national expertise and capabilities are available.

9. Southeast Asia (Thailand or Sumatra). This is a heterogeneous region where land-cover changes since 1960 have been significant (e.g. one of the most significant sources of biotic carbon dioxide other than Brazil). In addition to deforestation activities and its tropical environment, wetlands (and paddy rice) offer interesting possibilities from the perspective of radiatively active gases. It also offers the opportunity to test methodologies for wetlands. There is considerable remote-sensing support (SPOT and Landsat receiving station) and data availability is high (GRID; ITC-Holland). There exists demonstrated GIS and remote sensing capabilities in either of the host countries, and there exists retrospective and on-going land- cover mapping efforts using satellite data.

10. Eastern Africa. In this region of the northern half of Kenya, made up of mainly rangeland plains, and the adjoining part of the Southern Ethiopia highlands has come under severe deforestation, erosion, and changing agricultural use. Recent international programmes have collected systematic natural resources information, be it of relatively low resolution, has become available recently for the two areas (e.g., UNEP, Norwegian Aid for Development). This tropical semi-arid region with Substantial research facilities existing in Kenya are UNEP; Regional Centre for Remote Sensing and Mapping; KREMU; Unesco-UNEP's IPAL project. Northern Kenya is also an ICSU-CODATA testing area.

2.7 Action

The following action plan for this pilot study is proposed (Table 2). The general plan consists of an initial planning phase to be completed by early 1990, a five-year implementation phase with the first three years of intensive work followed by a two-year period of research leading to a final test of the methodology of land-cover classification (see Table 2.)

During the planning phase, the following items will be resolved:

* definition of land-cover classification;
* details of study plans (e.g., acquisition of remote-sensing data, procedures for acquiring ground truth (both for verification and validation), procedure for integrating remote-sensing output with ancillary data bases and with other global-change related activities, such as modelling;
* selection of initial algorithms;
* site selection;
* identification of research teams ;
* identification of funding sources;
* design test for global extrapolation.

The first three years of the implementation phase will include ground-truth observations and remote-sensing analyses. Development of a geo-registered land cover map is the initial goal. Ground-truth sites will be used to develop this data base and mapping product. Additional sites will be used to validate the methodology. During this phase, development of appropriate methodology regarding algorithms, spatial and temporal resolution, and verification schemes by high-resolution remote-sensing information will be conducted.

The final two years will be conducted at a much lower intensity, when remote-sensing data will be collected but ground-truth verification will be greatly reduced. These additional two years will provide a further test of the methodology relative to inter-annual variability and to extend results to regions outside the pilot study area leading into a global coverage. Application of results will be tested against modelling studies to insure compatibility of the land-cover data base and model requirements.

TABLE 2.
Time Table for Pilot Study
on
Land Cover Change

Tasks	Times	Responsibility
Project design	June/89	IGBP WG1 Pilot Study Science Comm. (PSSC)
Acquire existing global data	June/89	IGBP WG1 PSSC
Case-study site selection	June/89	PSSC
Science direction review	Spring 89	SC-IGBP
Project Manager in place	Summer/89	IGBP (Postdoc) at GRID
Project implementaion begins	Spring 1990	Pilot Study Research Team (PSRT)
Project evaluation first phase	Spring 1992	IGBP WG1
Continued monitoring and test of methodology	1992 through 1994	PSRT
End of pilot study	1994	IGBP WG1 / SC-IGBP

ORGANIZATIONAL RESPONSIBILITY

IGBP Data WG provides:

. Project design
. Project direction
. Science direction
. Project management
. Output development

UNEP-GRID provides:

. Data archiving facility
. Data, as available
. GIS/IP analysis facility
. GIS data analyst
. Office space, support for project manager
. Output disemmination
. International UN context

Remote Sensing Technologies Aid to Monitor Changes of the Land Surface

New methodologies will enable us to better monitor alterations to the Earth surface resulting from natural and human-induced changes to the global environment and the land surface. Remote sensing output coupled to computer models, which is augmented by in-situ surveillance and experimentation, and with new data handling techniques provide a unique opportunity to view the Earth surface and to interpret the changing patterns.

Rapid changes are occurring in a tropical forested area in Brazil, Rodonia, and provide a vivid illustration of the development of these technologies working in concert to provide a method to document the changing pattern of the land-surface. Research at the University of New Hampshire at the Institute for the Study of Earth, Ocean, and Space by Dr. David Skole and colleagues have utilized AVHRR and SPOT images to study land use changes during the past decade, and they have incorporated the data collected into a geographic information system to estimate areal extent of these changes. The following example is derived from this research.

A set of AVHRR images from Rodonia taken in September 1988 are depicted in Figures A through C. The images are composed of pixels approximately 1-km on a side and Figure A is approximately 512 x 512 pixels in area, the color bands are 4, 1, 2 corresponding to red, green, and blue, respectively.

An enlargement of the northern portion of Figure A is shown in Figure B. Note the long lines of clearing on the bottom the image, and the hydroelectric project on the top of the image, extensions from the bright yellow square are dikes. Figure C is a closer look at the area near the hydroelectric project. Note the coarse grained nature of the image.

Figure D, E, and F are SPOT images taken from approximately the same region and time of year in 1988 for Rodonia. SPOT images have a pixel size of approximately 30m to the side and provide a much greater resolution of the land surface. Temporal coverage is not as great as those provided by AVHRR. The image in Figure D encompasses approximately 3000 x 6000 pixels.

A closer look at the development in Rodonia is provided in Figure E, which depicts the lower portion of the area in Figure D at twice the scale.

At even higher resolution (Figure F) depicts areas of forest clearing and concentrated road construction in great detail. Unlike the AVHRR data, this image provides a much clear image of the pattern of clearing and the structure of the remaining forested area.

Remote sensing data can provide a "snapshot" of land management practices. Estimate of land clearance for 1985 (D. Skole, pers. comm.) was made using AVHRR data. In addition, overlain on the map are "hot spots" (white areas) from a single days image of Brazil indicating recent or ongoing areas of biomass burning (Figure G).

Time series of remote sensing data can provide an indication of the temporal pattern of land use. Two SPOT images were used to make the image in Figure H depicting the amount of forest conversion between 1986 to 1988. The image shows areas of forest (black) areas of secondary forest growth (yellow) areas of forest conversion prior to 1986 (green and orange), forest conversion area after 1986 (pink and blue), and areas of bare soil and human occupation (white).

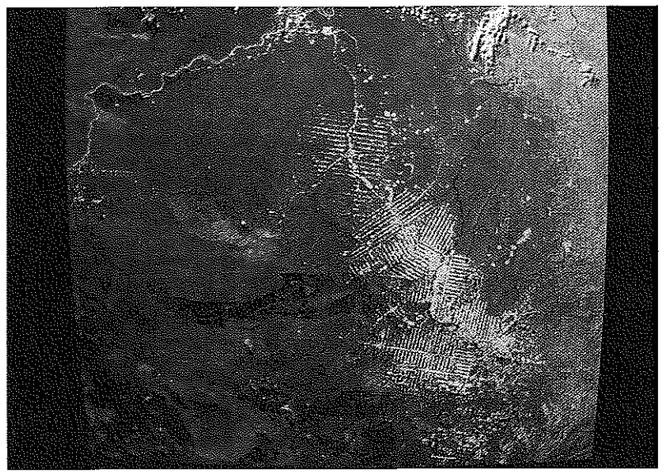

Figure A.

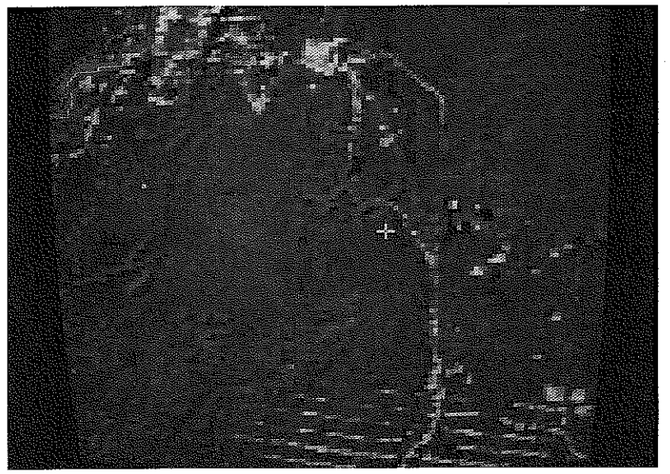

Figure B.

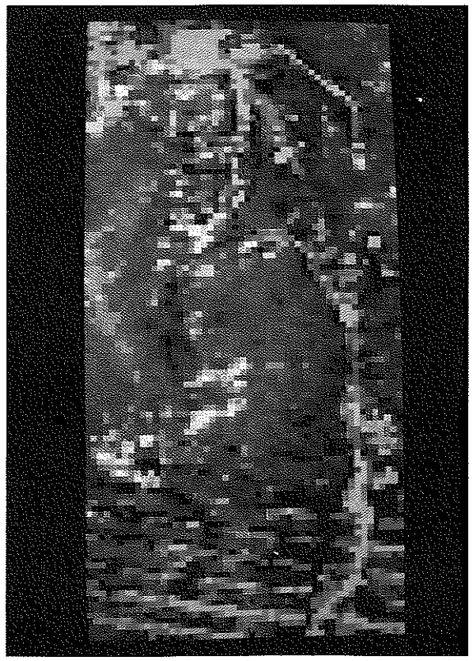

Figure C.

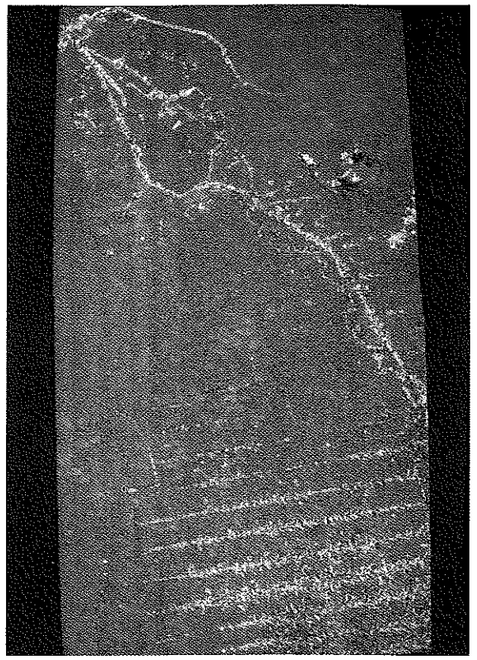

Figure D.

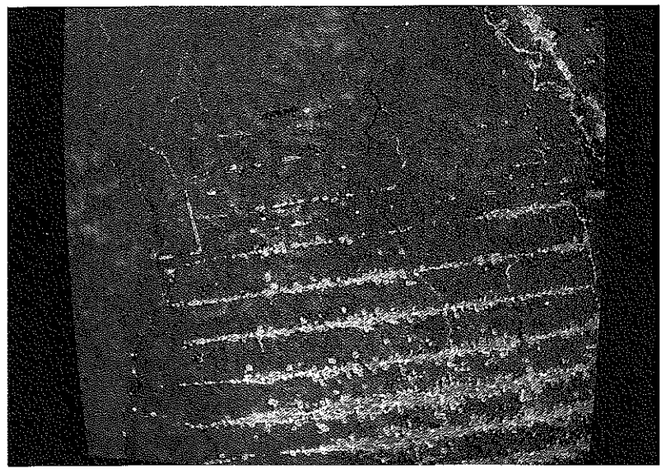

Figure E.

Figure F.

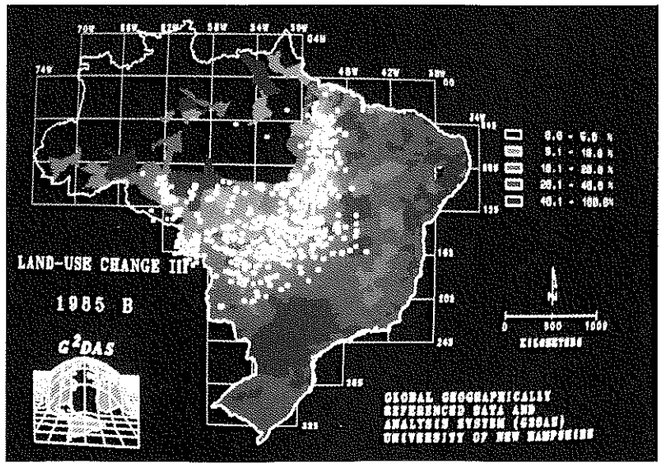

Figure G.

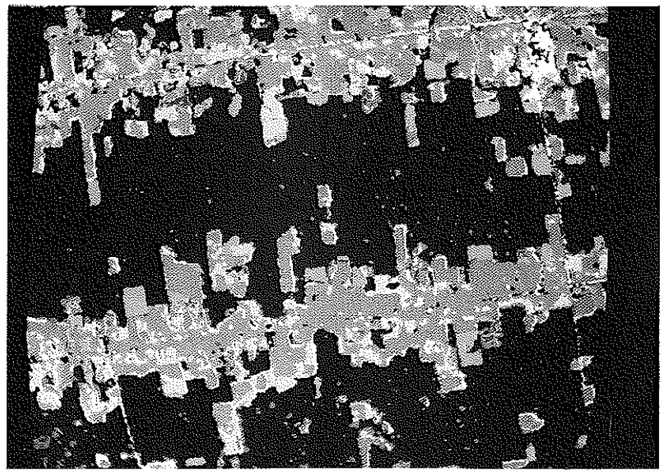

Figure H.

3 GLOBAL CHANGE DISKETTE PROJECT

3.1 Introduction

This project is designed to create and distribute on computer media to research groups, particularly in the developing countries, medium-resolution data sets of interest to IGBP. While the ultimate goal is to distribute global data sets, continental data sets will comprise the first two phases of the project.

Vegetation imagery (VI) of Africa for several years is chosen as an appropriate first data set, since the study of land cover and its changes can be related to many processes of global change and human activities. Display and utility software with raster geographical indexing capability will also be included as will several ancillary data sets to permit use of the VI images for some scientific studies. Training and discussion workshops will be arranged.

If this first phase is successful, data from South America and Asia will be added in future phases of the project and development of significant numbers of ancillary data sets will be undertaken; eventually, creation of data sets of high resolution and of high scientific interest on advanced computer media, such as CD-ROMs.

3.2 Objectives

* To develop an appreciation of the nature of global change problems, leading to understandings of relevant global-scale processes through study of significant regional-scale processes. The expectation is to develop conceptual frameworks to view the regional-scale processes in the global context. Vegetation imagery (VI), which is an available data set and relates to primary production, a large-scale process that is strongly influenced by climatic variability as well as human activity, is chosen as a suitable, feasible beginning of this effort.

* To develop an initial training course providing a hands-on use of software and hardware to manipulate the VI data sets, leading to development and identification of local/regional-scale research problems in many areas of the world, involving research scientists in universities and government research agencies.

3.3 Goals

* To familiarize users with the data sets to be used, software to display and manipulate the data, and associated hardware.

* To provide a road map of how to proceed to elaborate the first phase of the project to achieve the ultimate goal of stimulating undertaking of regionally and globally interesting research projects starting in the first phase but growing to the use of larger data sets in following phases.

3.4 Examples of Interesting General Questions

* Scaling - comparison of similar VI observed from different topographic regions, physical climatic regions or land-use management, using a range of scales, to study the scale-dependencies, if any, of interpretative procedures.

* Environmental controls - determine how climate versus edaphic or land-use practices control the VI signals.

* Statistical modelling - develop a global empirical model for biomass, productivity and turnover for various VI classes and use it to study climate, land-use and edaphic interactions with vegetation, which could also be classified and registered to grid points as indicators of climate change effects.

3.5 Examples of Regional Problems of Importance to the IGBP

* Biomass burning in tropical regions

* Land use as inferred from VI

* Water-storage capacity inferred from VI

* Relationship between VI and climate/meteorological variables

* Validation of VI to known ground-truth or aerial-photography data

3.6 Design Desiderata, Initial Phase

The first requirement is that a data set be chosen that is of substantive scientific content and that can be used to address the kinds of global and regional problems described above. It would be desirable to include a region where change is taking place and, if possible, a time period of significant global climatic perturbation along with pre- and post-perturbation data.

The second requirement is that a scientifically useful data set can be contained on a practical number of 5.25-inch double-density diskettes.

A third requirement is that user-friendly software is available that can be included in the data set. The software must be capable of displaying the image fields, with user-controllable color palettes; should allow the data to be changed in format, map projection, or resolution; and, if possible, should also allow zoom capability to allow small areas to be examined. Raster and possibly vector geo-referencing capability would also be desirable so that overlays of different data fields could be achieved.

3.7 Proposed Project Design

Choice of Data Sets. A 5.25-inch diskette holds 1.2 Megabytes of data, and a global display of VI at useful resolution of 16 x 16 km comprises some 2.4 M bytes; even with compression techniques, therefore, less than one global scene can be held on one diskette. Too many global scenes to be practical would have to be distributed to make scientific studies possible. It therefore seems impractical to distribute global data sets of VI on diskettes. CD-ROM technology is also ruled out, for practical and technical reasons, for this phase.

There is a clear need for adequate seasonal and annual resolution to capture the phenological nature of the vegetation. Monthly is deemed to be the minimum time resolution needed for adequate scientific use. As a consequence of these practical considerations, it is proposed to select one continental region for Phase I of the project.

Choice of Location. In view of the wide interest in Africa, and the availability of training possibilities by collaborating with UNITAR, Africa is proposed as the area for the first phase of the project. South America and Asia could be chosen for next phases.

Choice of Period. The archival storage of VI data involves certain processing and sampling decisions. In the early phases of the operation of the AVHRR instrument on the NOAA meteorological satellites, many changes were made in sampling and compositing the data, along with changes in instrumental calibrations. These incoherences in the data archives are understood and plans are in being to reprocess the NOAA AVHRR data to remove these inconsistencies.

Since April 1985, a more-coherent sampling and processing scheme has been in place. Moreover, an interesting El Niño event occurred in 1986/87, resulting in global climatic impacts. It is the plan of the WCRP TOGA project to reproduce the global atmospheric dynamic fields and the oceanographic data from this period on one or two CD-ROMs; these data sets will be an invaluable ancillary data source for study of the land-cover changes related to a major global atmospheric/oceanic perturbation.

Final Proposed Design. It is proposed that the initial data set consist of monthly blocks of data from the years 1985-1988. It has been ascertained that these 45 or so data blocks can be contained on 4 diskettes.

One additional diskette will be devoted to display and manipulation software, developed at Clark University, USA, and which is being made available to this project. One or two additional diskettes will contain some useful ancillary data. Candidate sets include: topography (max, min, mode), coastlines, soil map, land-cover-type map, demographic map, and climatic data. Only a few of these data sets can be prepared for the start of Phase I but, as they become available and transferred to diskettes, others would be distributed to participants.

3.8 Schedule

The data sets will be compiled in the second-third quarters of 1989, with the goal of producing a diskette set of some 8-10 diskettes by the end of the third quarter.

A pre-workshop discussion is planned to be held in the third-quarter of 1989 in conjunction with a UNITAR workshop, at which time the pilot data set will be demonstrated to research and administrative groups in Africa for feedback on project design and to potential participants.

A special Diskette Workshop is planned for the fourth quarter of 1989 or most likely first quarter 1990, at which time participants will spend one week with experts on becoming familiar with the software, mathematical analysis techniques, and use of the data sets for regional/local global-change studies. The data sets and software will be distributed to participants.

The detailed schedule is tentatively as follows:

1989

March-April - preparation of a detailed description (brochure) for distribution to potential participants

March-May - Information from ICSU, WMO, ISLSCP, etc., for use to compile list of potential participants

March-August - The data set will be compiled. The software is already available.

April-July - Collaboration will take place with UNITAR to agree on details for a September workshop in Accra. Collaboration will also be sought with groups in USA (e.g., the NSF-sponsored National Center for Geographical Information and Analysis, UC- Santa Barbara), France, Germany and UK to help organize and staff the Diskette workshop.

Late 1989 - At the UNITAR Workshop, the data set will be demonstrated, and further input will be obtained on which groups in Africa have enough background and could benefit from participation.

1990

Early 1990 - Diskette workshop, the exact time and place to be determined by UNITAR and IGBP Secretariat. January 1990 - Planning should begin for Phase II: select area, compile new VI data set, and begin to compile other related data sets.

Mid-1990 - Planning should be initiated for Phase III, e.g., investigate possibility of placing entire VI data on set CD-ROMs (weekly composites to provide cloud-free data, plus original daily channel data so that researchers can compile their own special-purpose data sets), investigate possibilities of donation of CD-ROM readers and suitable computers, etc.

Sometime in 1990 - Arrange a post-analysis workshop to compare results of Phase I and provide input for further phases.

3.9 Other Aspects

Extension of this project to eventually include the ocean colour data set has been recommended by the SC-IGBP.

In the course of discussing the Diskette project, several research groups in developed countries have asked for copies of the sets to experiment with them in their laboratories and using their software and related data sets. This will be valuable in that additional feedback will be obtained.

Moreover, there has been pedagogical interest in using the Diskette Pilot Data Sets. For example, one research professor at a major USA university would like to use this Phase I data set as a basis for developing a course for secondary-school mathematics students to teach them statistical-analysis methods. Much valuable feedback should come from such ancillary use.

4 END-TO-END SYSTEMS STUDY ON SURFACE TEMPERATURE DATA SET

4.1 Introduction

Surface temperature is a key parameter representing an integration of climatic and surface processes. Accurate averages over large areas are needed for monitoring changes in both the land and in the climate systems, for validating climate, and for inputs into biogeochemical models. An increase in the global surface temperature is predicted the greenhouse effect, and thus is an appropriate variable for monitoring. Similarly, change in the state or composition of vegetative land cover is likely to result in changes of the surface temperature.

While some global surface-temperature data sets exist (e.g., WMO, UNEP-GRID), they do not yet meet the needs of many envisioned global change projects. Deficiencies include: inconsistencies in the data set over time and space due to instrumentation differences; lack of consistent validation over the entire record (over 100 years); insufficient global coverage over the land and ocean before satellite remote sensing; and non-existence of an operationally produced, remotely- sensed land-surface temperature.

4.2 Towards Planning of an End-to-End Test on Surface-Temperature Data Sets

Many of deficiencies mentioned above could be overcome, or at least understood, if some of the scientific experts would combine talents and systematically eliminate or reduce these unwanted data-set discrepancies. As a first step towards this systematic process, the WMO and IGBP will hold a meeting of experts later this year. This meeting could be in conjunction with the next meeting of the IGBP Data and Information Systems Working Group, which will focus on oceanography. Scientists who understand the uncertainties in surface temperature measurements will be invited. The goal of this meeting will be to identify the deficiencies, to make recommendations to remove or reduce these discrepancies, and to provide guidance, where appropriate, for a more complete end-to-end system test for surface temperature.

4.3 Land Surface Temperature from Satellites

Measurement of land-surface temperature from satellites poses several very specific problems. There are a number of algorithms for retrieving surface temperature, taking into account corrections for atmospheric water-vapor absorption, and, in some cases, sub-pixel cloudiness.

* Satellites can make the observations at the required scales, but it is difficult to establish the validity of these data compared to the point measurements using conventional systems, precisely because of the scale differences.

* Land-surface heterogeneity contributes considerable uncertainty to the satellite measurements. This heterogeneity leads to differences in emissivity and

actual variations in the thermometric temperatures of components within a pixel.

* The non-linearities in the relationships between measurable quantities (radiation fluxes) and the desired variable (temperature) result in systematic biases which may be on the order of 1-2°C depending on the actual composition and geometric arrangements within a pixel.

* Variations in the horizontal and vertical distribution of water vapor in the atmosphere introduce variations on the order of 1-15°C. Current algorithms can probably reduce this uncertainty to 1-3°C.

4.4 Action

An algorithm intercomparison will be organized by ISLSCP in cooperation with the IGBP and would take place during a one year period between 1989-1990. Two major experiments have gathered data which can be used to test and inter-compare algorithm for space-based measurements and their relationship to ground measurements. They are HAPEX-Mobilhy (André et al. 1986) and FIFE (Sellers et al. 1988). Data sets from these experiments should be distributed to selected participants, who would derive standards products using their algorithms. After a defined interval, the participants should gather for a 3-4 day workshop to inter-compare results using different algorithms, to make recommendations for further research and to recommend interim operational procedures. Following this workshop, the HAPEX II programme, which is being planned from 1990 to 1994, will be an excellent opportunity to improve and validate the algorithms of the extraction of land surface temperature from satellite data at large scale and to demonstrate the feasibility of an "end to end system."

Time schedule:

IGBP approval	June/89
Planning meeting	September/89
Funding application to ISLSCP	September/89
Funding received	January/90
Participant invitations	January/90
Data shipped	March/90
Workshop	August/90

5 IGBP DATA DIRECTORIES

5.1 Data Directories

Global change scientists will need access to global data sets. Interdisciplinary work, in particular, will be impeded by lack of information on existing and planned data sets, including what they are and how to obtain them. In this regard, an easily accessible environmental data set directory for global change will help, particularly in the early phases of IGBP. For discussion purposes it was agreed that a directory could contain high-level information on data sets such as the parameter name, who compiled the data set, what are the space and time durations, where the data set is located, and how to access it. An inventory is a very detailed description of a data set, record by record, or image by image, and is normally developed in conjunction with the data set.

The types of data sets to be considered for such a directory will be global in nature, or deemed representatives of global conditions. The data sets should have uncertainties well within the change anticipated; that is, all data sets should pass F. Bretherton's 20 year test: after 20 years can we tell with confidence that the changes observed to have occurred are real rather than artifacts of some aspect of measurements or analysis process?

Data sets that meet these requirements can be of four types: those based on sustained global measurements; those based on process studies to understand particular phenomena or develop improved algorithms for models; those data sets based on past records, both instrumental and proxy; and those data sets or fields based on model results.

Directories of data sets necessary for other programs exist, and they need to be considered when developing a global change directory. These directories were not constructed with global change in mind, and are not sufficient. WMO's INFOCLIMA, and UNEP's INFOTERRA are examples of successful international directories. A directory of directories of global-change data sets is being developed in the U.S. and may be of interest. The parameters necessary for global-change study have not as yet been identified for IGBP. For the moment the global variables listed by the U.S. Earth System Science Committee serve as a guide.

5.2 Action

It was agreed that Greg Withee would work with Roberto da Cunha, Victor Boldirev and Harvey Croze to develop further a directory scheme for IGBP. The guidance given was to initiate discussion of a plan which should build on existing systems where feasible. The effort should probably start by identifying the few global data sets that exist. One single directory would not be useful for all countries, but the directory should be computerized, easily updatable, and easily searched. The directory plan should include consideration of significant ongoing scientific input, for example for selecting subject classifications and judging the relevance of the material. The plan should include steps for phased implementation, and ongoing management structure, which should include consideration of ICSU's World Data Center System. The plan will be presented by Greg Withee at the next IGBP Working Group meeting in approximately six months.

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APPENDICES

APPENDIX A

PARTICIPANTS
IGBP WORKING GROUP MEETING
FOR
DESIGN OF PILOT STUDIES FOR DATA
AND
INFORMATION SYSTEMS

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APPENDIX B

Glossary

AVHRR (Advanced Very High Resolution Radiometer):

An instrument carried aboard the U.S. NOAA series of polar orbiting satellites, designed primarily for imaging clouds, but which has several spectral channels or observational parameters which can be used to derive products such as vegetation index.

Land Cover:

The physical/biological manifestations of natural ecosystems or human land use which may be evaluated by remote sensing. In practice this means a broad classification of vegetation type such as: Forest, Scrub, Grassland, Desert, Arable land, Wetlands, Ice and snow, Urban. The classification scheme has to be carefully constructed to ensure that the classes are important for global change studies, can be obtained from (initially) AVHRR data, and are all-encompassing on the global scale.

Land Use:

A modification of land cover from a human perspective, e.g. Savannah versus Pasture Lumber forest versus Orchard or Plantation, Irrigated versus Non-irrigated Large ranches versus Smallholdings.

Mapping Grid:

A matrix of 1 km x 1 km squares to which satellite survey data (1 km resolution) is geo-referenced and interpolated for analysis.

Stratified Random Sampling:

A procedure for randomly selecting samples for statistical analysis, contingent upon predetermined data- dependent categories.

APPENDIX C

Acronyms

AVHRR	Advanced Very High Resolution Radiometer (NOAA)
CODATA	Committee on Data for Science and Technology
ENSO	El Niño - Southern Oscillation
FIFE	First ISLSCP Field Experiment
GIS	Geographic Information System
GRID	Global Resources Information Database (United Nations)
HAPEX	Hydrologic Atmsopheric Pilot Experiment
HRPT	High Resolution Picture Transmission (NOAA)
IBM	International Business Machines
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Programme: A Study of Global Change
ISLSCP	International Satellite Land Surface Climatology Programme (Project)
JPL	NASA/Jet Propulsion Laboratory
LANDSAT	Land Remote-Sensing Satellite (USA)
MSS	Multispectral Scanner (Landsat)
NOAA	Natiopnal Oceanic and Atmospheric Administration (US)
SC-IGBP	Special Committee for the IGBP
SPOT	Systeme Probatoire de l'Observation de la Terre (France)
TOGA	Tropical Oceans Global Atmosphere Experiment
UNEP	United Nations Environmental Program
WDC	Panel on World Data Centres (Geophysical and Solar)
WCRP	World Climate Research Program
WMO	World Meteorological Organization

IGBP Reports

No. 1. The International Geosphere-Biosphere Programme: A Study of Global Change. Final Report of the Ad Hoc Planning Group, ICSU 21st General Assembly, Berne, Switzerland 14-19 September, 1986 (1986)

No. 2. A Document Prepared by the First Meeting of the Special Committee, ICSU Secretariat, Paris 16-19 July, 1987 (1987)

No. 3. A Report from the Second Meeting of the Special Committee, Harvard University, Cambridge, MA, USA 8-11 February, 1988 (1988)

No. 4. The International Geosphere-Biosphere Programme. A Study of Global Change (IGBP). A Plan for Action. A Report Prepared by the Special Committee for the IGBP for Discussion at the First Meeting of the Scientific Advisory Council for the IGBP, Stockholm, Sweden 24-28 October, 1988 (1988)

No. 5. Effects of Atmospheric and Climate Change on Terrestrial Ecosystems. Report of a Workshop Organized by the IGBP Coordinating Panel on Effects of Climate Change on Terrestrial Ecosystems at CSIRO, Division of Wildlife and Ecology, Canberra, Australia 29 February - 2 March, 1988. Compiled by B. H. Walker and R. D. Graetz (1989)

No. 6. Global Changes of the Past. Report of a Meeting of the IGBP Working Group on Techniques for Extracting Environmental Data of the Past held at the University of Berne, Switzerland 6-8 July, 1988. Compiled by H. Oeschger and J. A. Eddy (1989)

No. 7. A Report from the First Meeting of the Scientific Advisory Council for the IGBP. Volumes I and II. (1989)