LTER Technology Report
for the
LTER Strategic Plan
by
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This report follows the Shugart Committee Report which identified the scientific issues being addressed by the LTER sites and made recommendations for network-wide capabilities to address those issues. The following is a summary of those issues and recommendations to lead to the charge given to the Technology Committee (TC).

The scientific issues identified by the network are:

1. Research topics in spatial variability and pattern;

2. Documenting and interpreting long term temporal variability in ecosystems;

3. Developing interbiome comparisons; Developing and validating simulation models, new classes of spatial simulators.

The technology recommendations made by the Shugart Report were:

1. Acquire GIS capability across the network;

2. Develop network remote-sensing analysis capability; Augment WAN and LAN in the LTER system.

These issues and recommendations formed the basis for the charge given to the Technology Committee by Jerry Franklin. The following summarizes that charge and set the conditions for the discussions that followed:

1. The primary research goals driving the technology requirements across the LTER network are;

a. assessment of global change

b. comparative studies of ecological phenomena and theories

2. Network technology needs should be developed based on the ability to;

a. communicate and transmit data

b. manage large data sets

c. conduct complex spatial analyses

3. The network should look beyond computing abilities identified in the Shugart Report to;

a. advanced instrumentation

b. remote sensing

4. Technologies should be identified that are;

a. available at all sites

b. available at one to a few lead sites. The lead site concept should consider;

1. objectives of the lead site Concept

a. service to network

1. process data

2. support/aid in specific analyses

3. unusual equipment
b. education and training

c. develop and/or follow advancements in various fields

2. criteria for the lead site concept

a. responsibility

b. accountability

The discussions of the TC not only identified important technologies but research endeavors that will be critical in attaining the goals of the network. Those make up the remainder of the report. The TC also ranked the topics of this report based on the following criteria (in order of importance): relevance to LTER goals; temporal urgency in implementation; expertise available; amount of time needed to implement; cost. The order of the following sections reflects the ranking with the most important and urgent first.

1. ACQUISITION OF SATELLITE IMAGERY FOR ALL SITES

The high ranking of this category resulted from the discussions of the TC about the importance of this technology to the network. Conclusions generated by the committee were: Acquisition of satellite data (Landsat TM) should proceed immediately (i.e., 1989 growing season) to include 2 scenes per site (pre and peak growing season).

- All sites should be encouraged to acquire at least a base level hardware/software capability forprocessing remotely sensed spectral data.
- A system of regional remote sensing centers should be established for large data processing services, intersite comparative studies, and training facilities.

Scientific Rational:

Satellite remote sensing is a technology identified by the committee as having important near-term and long-term value to the inventory and monitoring needs of the LTER network. Satellite acquired spectral data from the visible, near IR, mid IR and thermal IR wavelengths are presently available for each of the LTERs, as is the hardware and software necessary for the processing and analysis of that data. Remote sensing developments now taking place, and others expected in the near future, will make available a wider range of spectral data with increased spectral and spatial resolution.

Satellite remote sensing can be used for inventory, monitoring, change detection and inter-site comparison. Processed spectral data can be overlaid, merged or integrated with point, line, or polygon data within a geographic information system (GIS). Of particular value to the LTER will be inter-site and interbiome comparisons of ecological phenomena. Satellite remote sensing has immediate application where large area or regional data are required. Comparative studies will be an important LTER program contribution to the assessment of global change. Satellite remote sensing of LTER sites, in conjunction with the ground data being collected by the LTER network, provides a program link with many of the regional or global research programs presently underway nationally and internationally (i.e., the planned Earth Observation System

(EOS) of NASA, the International Satellite Land Surface CIimatological Program (lSLSCP) of NASA, the International Space Year (lSY) of U.S, State Department, and the First ISLSCP Field Experiment (FlFE) of NASA). Each of these program links offers the opportunity for data exchange and comparison using remotely sensed data, thereby expanding the resource base available to each LTER site.

Within or between LTER sites, spectral analysis of remotely sensed data will directly support the study of spatial variability and spatial patterning. Remotely sensed data provides an important tool to quantify and map land cover through spectral separation and classification. Comparative studies will require a standardized protocol for spectral data processing, to include methods for radiometric, geometric and atmospheric corrections. These corrections calibrate raw spectral data for a conversion to units of watts per square centimeter, and reference these data to geographic coordinate systems (i.e., UTM).

There presently exist several operational space based commercial sensors as well as a number of sensors under development and being flown on airborne platforms which are being considered for future space flights. The two most familiar satellites are Landsat and Spot, both commercially available systems. Both satellites offer "small scale" and "mid scale" data on a regular cycle. Each satellite has two scanners on-board. Landsat has a 7 channel scanner with 30 meter resolution (thematic mapper or TM) and a 4 channel scanner with 80 meter resolution (multispectral scanner or MSS). Spot has a 3 channel scanner with 20 meter resolution (high resolution visible or HRV) and a single panchromatic channel scanner with 10 meter resolution. Landsat offers a 16 day repetitive cycle and Spot has a 26 day cycle with a possible 5 day repetitive capability if an off-nadir viewing angle is acceptable. A third spaceborne system, the Advanced Very High Resolution Radiometer (AVHRR), operated by the National Oceanographic and Atmospheric Administration (NOAA), acquires climatic data daily, but has low spatial resolution (600 meter or 1000 meter). The data from this sensor is finding greater applications in global research. Several sensors now in development or flown on airborne platforms will become integral parts of forthcoming research programs (e.g., EOS). These scanners offer a wider range of spectral and spatial resolutions than is presently available. For example, the Thermal Infrared Multispectral Scanner (TlMS) is a 6 channel thermal scanner with up to 10 meter resolution, and the Airborne Visible Infrared Imaging Spectrometer (AVlRlS) is a 224 channel scanner with 20 meter resolution. These are examples of "mid to large scale" data acquisition systems. Other systems are under development and are part of the continued research that is going on in remote sensing. Table 1 identifies the number of channels and the spectral range of several available sensors.

The remote sensing technology described has been developed for selectively collecting spectral data. Once the data have been acquired, a hardware and software intensive image processing technology must be used to process and analyze these data. Several image processing systems are in the public domain. A significant difference in image processing systems is their ability to process large data sets and to merge or overlay those data sets with point, line and polygon data. These systems can roughly be divided into two groups, those able to handle large, multichannel data sets from satellite or from airborne platforms, and those able to handle small multichannel data sets from satellite platforms. The differences are both economic and convenience. Systems able to handle large, many channeled data sets require more computing capability, programming and operator support. Managing extensive enhancement and classification systems requires a person dedicated to keeping the system hardware and software maintained and available. These are expensive commitments. The smaller image processing systems, which are usually more user friendly and operate on smaller, less expensive computers, are most valuable to the researcher with limited funds and small scale applications.

Two examples of user friendly systems which can perform image analysis at levels useful to LTER research are the ERDAS and Terra Marr image processing systems. ERDAS has a raster based GIS and is also able to rasterize data from ARC/INF0, a vector based GIS. Image processing systems for larger data sets, as will be required for inter-site and inter-biome comparisons, or for processing data from AVIRIS or other multichannel airborne scanners, are Earth Resources Laboratory Applications Software (ELAS) developed by NASA, Land Analysis System (LAS) developed by NASA and now being expanded in cooperation with USGS, and Interactive Display and Image Manipulation System (lDlMS) , a commercial software developed by Electronic Systems Laboratory. There are other image processing systems than those mentioned, but these are used widely and respond to LTER needs and requirements.

Advantages/Disadvantages:

The advantages of using remote sensing technology in the LTER program are many. The acquisition of data from satellites is nearly instantaneous and encompasses thousands of square miles. When data is collected so rapidly there is minimal spectral variability caused by sun angle changes or climatic variation as a result of prolonged acquisition time. The data acquired is within specific spectral bands providing a selectivity and increased flexibility when characterizing land cover environments. Many of the spectral channels are outside of the visible spectrum and are very responsive to vegetation cover conditions. These responses can be quantified and compared temporally or with other

TABLE 1.

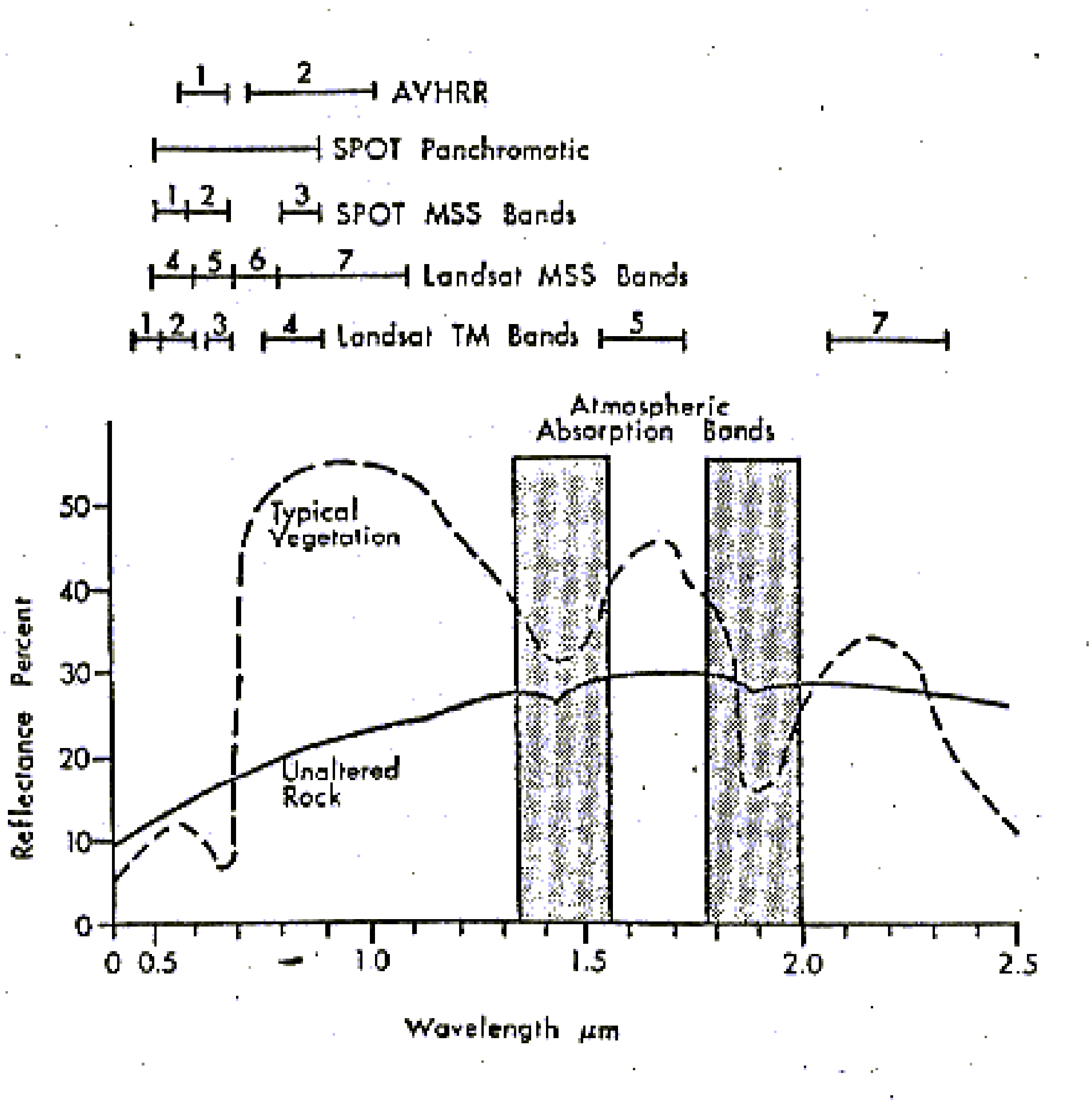
A. Small and mid scale satellite data acquisition systems

- Sensor Resolution Channels Overpass
    - Visible Near IR Mid IR Thermal
    - AVHRR 1Km/4Km 1 1 1 1 Daily
    - Landsat MSS 80m 2 2 16 Day

    - Landsat TM 30m 3 2 1 1 16
- SPOT HRV 20m 2 1 5-26 Day
    - SPOT Pan 10m 1 Same

B. Mid-to-large-scale airborne data acquisition systems.

- TIMS 10m 6
- AVIRIS 20m



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environments. These spectral responses can be related to field acquired spectra for extrapolation within the study site or other study sites. All the data is in digital format which can be radiometrically and atmospherically corrected. These quantified spectra can then be compared with spectra from within a biome as well as between sites and with ground/field collected spectra. The digital data can be geometrically corrected providing for very accurate location of field derived information and for integration within a GIS. The digital map data can also be easily scaled for analysis or field use. As the research in remote sensing sensors and image processing software produce new developments and

applications, it expands the tools available for use to each LTER site.

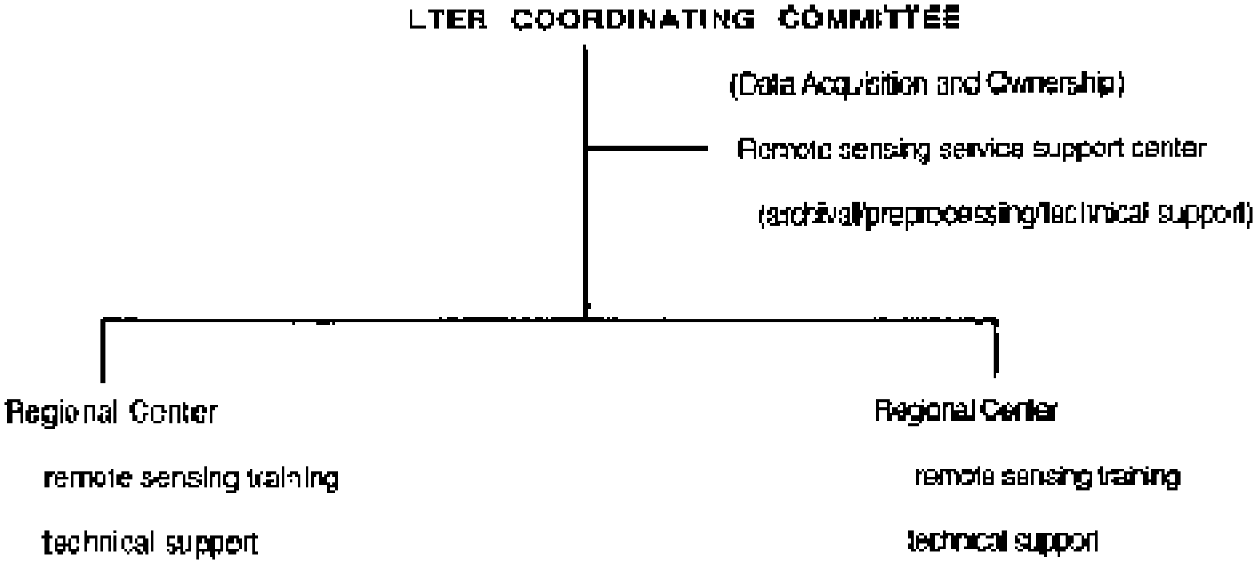
There are disadvantages to the use of remote sensing technology as a tool for the LTER sites. it is expensive, in the sense that a knowledge base is required to use and understand it, and a commitment must be made to keeping current with the expanding sensor, software and hardware technologies. Image processing systems can be very expensive in personnel costs necessary to operate and maintain the system as well as for hardware and software maintenance and upgrades. If care is not taken unnecessary energy and funds can be expended on maintaining and updating the tool rather than on the use of the tool. The cost of remote sensing can be controlled to some extent by utilizing smaller scale image processing systems which are user friendly. This will reduce the time required in learning the software and in keeping current with it but introduces limitations in that certain data processing options are not available, and smaller data sets must be used. These limitations could be overcome by strategically designing a series of remote sensing centers for the LTER network, each having more extensive software/hardware facilities that could be accessed by other network users.

Lead Site Concept:

One alternative is a coordinated support system for hardware, software and data acquisition that could be drawn upon as needed by any of the LTER sites. This would require a service center and a lead site or sites with the direct involvement of the LTER Coordinating Committee. The satellite data from Landsat and Spot are copyrighted and have limitations upon the duplication and users of each data set purchased. If data are purchased by an individual site it can be used by that site's research team but could not be copied or sent to a second site for study. This restriction of data use would offset one of the more important benefits to using remotely sensed data for comparative study either now or in the future. By having the LTER Coordinating Committee act as the purchaser and agent for the data, all LTER sites could access the data as long as it was within the scope of site or inter-site research.

Implementation:

By establishing a remote sensing support center responsible to the LTER Coordinating Committee the data could be archived as well as preprocessed in response to the data and technical needs of each LTER sites or lead site(s). Utilizing a service support center would also free many of the LTER sites from the acquisition of unnecessary image processing equipment and related training and maintenance. Should more image processing be required than can be performed at a site, the center could provide that service. Those services could also be well supplied if one or two LTER sites were to act as training and support centers. Regional centers would reduce the travel time and expense as well as stimulate inter-site relationships. Through a service center and several regional centers the technical support and training workload could be distributed. Equipment needs could be reduced to smaller image processing systems for most of the sites and expanded systems for the service and regional centers. This arrangement allows for differential needs to be met by each of the sites at the time they are able to use them. The following diagram outlines one arrangement for a distributed remote sensing system with one service and two regional centers.



The service support center, in coordination with each LTER and the coordinating committee, orders all satellite data. The data is inventoried upon its arrival and the LTER sites are notified. All site data is preprocessed (atmospheric, radiometric and geometric corrections) and archived along with the original data set. The service center along with each regional center will be available to support the technical needs of each site. Should there be a need for training assistance, the regional centers are available.

Recommendations:

The recommendations arrived at by the Technical Committee for remote sensing are to acquire satellite data, preprocess the data, archive the data, and establish a remote sensing network to implement the program. Landsat data for the spring and/or peak growing season of 1989 should be requested immediately because of expected unusual environmental conditions during this strong La Nina year. Should there be delays in the implementation of an LTER remote sensing program, the data will have already been acquired and available for use this year versus the 1990 field season. The data should be preprocessed and archived, making it available to those LTER sites able to employ remote sensing immediately. Acquiring data this year also may offset a possible landsat satellite failure and data loss before the next satellite is deployed. A satellite failure is not totally unexpected due to the age of those presently in orbit. Landsat 6 is not proposed for launch until 1991. The establishment of the remote sensing network needs to be dealt with by the LTER Coordinating Committee as soon as possible to provide time for the sites to review their needs and requirements and identify plans to use remote sensing in their research.

2. BIOSPHERIC/ATMOSPHERIC INTERACTIONS AND MEASUREMENT

Technologies Required to Incorporate Biosphere/Atmosphere Interactions

Into LTER Sites.

The evolution of biology and the evolution of the earth's atmosphere are intimately intertwined. Until the processes which link biology and atmospheric chemistry are understood it will be impossible to predict the consequences of global anthropogenic activity; to anticipate the changes that are occurring to the chemical composition of the atmosphere and to estimate the magnitude of the feedback effects of climatic change on the biological cycling of key atmospheric trace gases.

Importance of Trace Gas Measurement to LTER :

An understanding of trace gas cycling is integral to a good understanding of ecosystem structure and function. Knowledge of trace gases fluxes can be critical to a good understanding of energy balances and C, N, and S cycling rates. For example, emissions of isoprene, a five carbon compound emitted by some vegetation species, can represent five percent of the carbon and ten percent of the energy fixed by plants. Failure to consider emissions of isoprene and other organics emitted by vegetation would lead to erroneous conclusions about such critical questions as ecosystem carbon accretion. Trace gas fluxes can also represent a significant nutrient transfer to or from an ecosystem. Examples of gases that could potentially fall into this class of compounds include nitrogen containing gases such as ammonia, nitrous oxide, nitrogen dioxide, organic nitrates, nitric acid and possibly some sulfur gases such as hydrogen sulfide, the mercaptans, and sulfuric acid. Most biologically produced trace gases are the result of very specific processes. Changes in biological trace gas emissions are affected by subtle interrelationships between species composition temperature, nutrient status, carbon allocation and moisture. Measurements of shifts in flux rates and the trace gas species composition of the atmosphere can therefore serve as an observational tool to integrate scales from individual microsites to an entire landscape. For example the terpene composition of the atmosphere could be a good indicator of relative vegetation species abundance. On a larger scale, ambient measurements of specific biologically produced trace gases may provide the first verification of global climate change. In addition measurement of trace gas fluxes can often serve as surrogates for more difficult ecosystem process measurements. Measurements of soil methane flux (an indicator of anaerobiosis) and the production of ethylene by plants (often an indicator of stress) are examples of trace gases that are potentially useful in this respect.

Trace gas measurements at LTER's are necessary in order to define the chemical climatology of the site. This is critical for the definition of a baseline from which to indicate long-term change. It is also important to define the chemical climatology so that anthropogenically produced trace gases effects can be recognized. Some anthropogenically produced trace gases can supply significant inputs of nutrients (such as fixed nitrogen). They can also have direct pollutant effects. Ozone, produced as a result of the emission of oxides of nitrogen and hydrocarbons is an example of a potent phytotoxin capable of long-range transport to apparently "remote" pristine sites. Even at low doses ozone could lower plant resistance to facilitate disease and insect outbreaks. In the long run, anthropogenic emissions of sulfur dioxide and the resulting deposition of sulfuric acid could drastically alter successional patterns. Failure to recognize these influences will undoubtedly prohibit the development of accurate models which can be used to predict ecosystem structure and function.

Finally, trace gas fluxes provide valuable information about ecosystem spatial and temporal variability. Since many trace gases are produced as a result of micro-scale processes, flux measurements can identify inter- and intra-site variability that could be difficult to recognize any other way.

Importance of LTERs to the Understanding of Trace Gas Cycles:

The LTER network provides a unique interdisciplinary framework for the study of trace gas fluxes. The LTER's provide relatively long-term records of biologically important variables which can serve as a foundation for understanding relationships between fluxes and biology. Long-term records of soil chemistry, vegetation composition, carbon allocation and nutrient cycling as well as records of physical parameters such as temperature, rainfall and solar radiation have been beyond the means and scope of most trace gas flux measurement programs in the past.

In addition , the LTER sites provide the opportunity to focus the disciplinary expertise of scientists in widely different fields in a way that can allow a synthesis of interdisciplinary understanding. The framework of the LTER program is ideal for the coordinated effort that is required if we are to be able to understand and predict global change.

Many of the LTER's are excellent candidate ecosystems to study fluxes of trace gases that are important to the chemistry of the atmosphere. Some trace gases are important because they are longlived greenhouse gases that can cause direct changes to the radiation balance of the atmosphere. Direct greenhouse gases include methane, nitrous oxide and carbon dioxide. Other biogenic trace gases are important because they can affect the oxidant balance of the atmosphere through the production and destruction of ozone and hydroxyl radical. Often the exact chemical pathway is determined by reactions with anthropogenically produced compounds.. This in turn affects the atmospheric fate of many of the greenhouse gases. For example, although the atmospheric lifetime of isoprene (a vegetation emission) is typically less than one hour, it is so reactive that it can dominate local and regional oxidant chemistry. If the oxides of nitrogen (NOx) are present (often as a result of anthropogenic emissions), isoprene can result in the production of large amounts of ozone. If there is little NOx, isoprene can serve as an ozone sink. Still other trace gas fluxes are important because the intermediate products of their reaction sequences in the atmosphere may have important chemical and/or biological effects. Examples of each of these compounds is listed in table 2. As can be seen in table 2, an understanding of atmospheric chemistry requires an understanding of biological as well as chemical rate constants. LTER's can provide the ecological expertise to link trace gas fluxes with biological processes. This knowledge can then be used to establish a framework for global extrapolations.

In summary, both atmospheric chemists and biologists will benefit by collaborating at LTER research sites. Trace gas measurements are required for an understanding of ecosystem structure and function. The expertise available at LTER sites is required for atmospheric chemists to link their measurements to the biology that often controls the fluxes. The ultimate goal is to build biologically based process models which can be combined with models of atmospheric chemistry and global circulation models to achieve interactive predictive ability.

The LTER's provide a good initial foundation for that endeavor.

Table 2.

Examples of Key Trace-Gases

Biogenic Emissions Intermediate Products Anthropogenic

CARBON isoprene, terpenes acids, aldehydes, co

hydrocarbons,

methane, co_2, co organic nitrates co, co_2

NITROGEN ammonia, N_20, nitric acid, PAN, NO_x $N0_x$, N_20,

NO_x ammonia

Sulfur H_2S, mercaptans, $S0_2$, sulfuric acid, SO_2, sulferic

COS aerosol acid, aerosol,

COS

Recommendations:

At the present time, only a relatively few LTER's have the capability to make trace gas measurements. This panel recommends a three-phased approach to alleviate this deficiency. Phase I will involve the establishment of a core of essential ambient air measurements made at each site in order to define the chemical climatology and to identify potential anthropogenic influences on ecosystem dynamics. Phase II will require the deployment of simple enclosure technologies in order to characterize each site with respect to its emissions of key trace gas species. This will provide a baseline of emissions which will allow assessments of short and long-term ecosystem change and provide comparative ecosystem information with respect to both inter- and intra-site variability. Phase III will involve the deployment of sophisticated micrometeorological flux measurement equipment and the coordination of research programs across the disciplines of biology, micrometeorology and atmospheric chemistry . This phase will help to integrate scales of space (small enclosures versus landscape-scale measurements) and time to help refine model inputs.

PHASE I

Phase I can be considered the start-up phase. It should begin as soon as possible. The start-up phase will involve the establishment of a uniform climatology data base which incorporates the basic weather data currently being collected at each site into a uniform data base accessible by all participants. During this phase tabulations of local wind fields and trajectory analysis should be completed for key times of the year that intensive experiments are to be conducted.

Phase I also includes the establishment of basic monitoring capabilities for selected trace gases at each LTER. Instrumentation will be chosen that can provide a direct record of site air chemistry. In addition the instrumentation chosen must be easily obtainable, it must operate relatively unattended and must not require specialized technology to deploy and maintain. A list of candidate chemical species to be continuously monitored includes ozone, condensation nuclei, methane, carbon monoxide and carbon dioxide.

Ozone is important because, as previously mentioned, it is an effective phytotoxin. Ozone is also an indicator of intermediate range chemical transport and a key component of atmospheric chemistry models. In addition continuous instrumentation with which to measure ozone concentrations in the atmosphere is readily available. Condensation nuclei measurements provide a simple way to asses the importance of local point sources such as car exhaust, chimney emissions and other combustion sources on the chemistry of the site.

Methane measurements will provide valuable data against which current models of global methane production can be tested. Currently few long-term records of continental methane measurements are available. In addition, methane measurements may help to indicate the presence of strong local natural sources. Carbon monoxide is a good tracer of airmass origin and history. In addition carbon monoxide measurements are a necessary input to models which are used to estimate atmospheric hydroxyl radical. Hydroxyl radical is very difficult to measure directly, yet it controls the fate of many tropospheric trace gases.

Carbon dioxide measurements are important because they can provide clues about photosynthesis and respiration. In addition, carbon dioxide measurements can also indicate strong local combustion sources.

Each of these measurements is relatively easy to make and each contributes unique diagnostic capabilities. Although any one species would not be definitive, together this suite of measurements provide information from which the chemical climatology of each LTER could be accurately inferred.

PHASE II

Phase II of the program requires the deployment of simple enclosure technologies for the characterization of selected trace gas fluxes. The enclosures would be deployed systematically during key periods of intensive study. Data would be useful to define the emission baseline and to identify and characterize inter- and intra-site variability. It is proposed that this phase be initiated during the second year of the program.

Phase II will require the participation of an entity such as NCAR to provide training in enclosure deployment. This could be done early in the summer of year two through the medium of a summer training course colloquium. The program would include experienced researchers invited to train graduate student field personnel through demonstrations and lectures.

In addition, transfer of analytical methodologies to selected key LTER's would also be initiated. These sites and participating National Laboratories and Universities would provide analytical services as individual LTER's acquire the necessary measurement capabilities. initially enclosure measurements should be made of gases such as methane and nitrous oxide. These compounds are relatively easy to measure and are relatively stable in storage containers. Samples of the dominant vegetation types at each site should also be enclosed to determine emissions of hydrocarbons such as isoprene and terpenes. These compounds can provide fingerprints for vegetation species determination in addition to their importance to atmospheric chemistry. Also during Phase II a survey of each site should be made to consider its potential suitability for micrometeorological flux measurements.

PHASE III

During Phase III micrometeorological flux tower facilities would be constructed at sites identified as suitable during the Phase II survey. In addition selected LTER's would begin initial micrometeorological flux studies. It is likely that National facilities such as the ASTER (Atmosphere/Surface Turbulent Exchange Research) facility at NCAR could be deployed for an intensive research program at a few selected LTER's each year.

Phase III would be ongoing and would include the continual development of measurement capabilities within LTER's. However although each site should be self-sufficient for a core set of measurements, it is unrealistic to expect them to maintain state of the art capabilities in the measurement of every important trace gas. A critical part of Phase III will therefore be the coordination of research programs involving atmospheric chemists, micrometeorologists, modelers and biologists at LTER sites. Additional technologies may become available by this phase to allow cross-site studies at various scales (FTlR, LIDAR, see section). These studies could develop relationships between the different gas flux and meteorological techniques.

3. PROCESS MODELING AND SPATIAL ANALYSES

Process Modeling with Emphasis on Spatial Modeling, Geostatistical Analysis,and High-Speed Computing in Ecosystem Research at LTER Sites

Scientific Rational:

Long-term ecological research mandates ecosystem-wide investigations conducted overlong-time periods by investigators with a broad diversity in disciplinary backgrounds. One of the global objectives of LTER is to be able to predict trends in ecosystem performance and trends in ecological phenomena. Add to this the objective of addressing spatial patterns of temporal dynamics of organisms and physical attributes, and there is a recognizable need to apply the most current and sophisticated technology to adequately address these objectives. Two objectives stand out:

1. to attain goals of addressing ecosystem analysis through prediction of ecosystem performance at multiple scales of resolution, and

2. to address issues in the temporal and spatial dynamics of physical features and organisms atmultiple scales of resolution in complex ecological landscapes.

It is recognized that long-term strategies and philosophies must be developed to optimize the use of new technological developments in the following areas to be successful in complex landscape assessment:

Area #1: Spatial statistics or geostatistics are systems to analyze the relationships between experimental samples at different locations in the ecological landscape.

Area #2: Geographic information systems to enable analysis of interrelationships between complex spatial landscape attributes measured by: sampling points in the landscape; acquiring satellite imagery to measure thermal, physical, and biological features and by digitizing images of patches with similar landscape properties. Image processing techniques will be instrumental in a wide array of data acquisition methods.

Area #3: Simulation modeling: models of ecosystem process at spatial resolutions provide the best assessment of current state of information. Models need to be developed so they project spatial distributions of processes through time and validation procedures require new concepts in modeling approaches.

Overview of Technologies Available:

Rapidly advancing technology is arriving in a timely fashion to allow investigators to study, relate, model, and display the spatial dynamics of complex interacting ecosystem components. These technologies, because of their spatial component, will heavily tax current systems of computing and modeling in the following ways: most of the operations performed in the process of geostatistical/statistical analysis and geographic information systems, including satellite image analysis, are:

1) extremely process intensive and eventually the most powerful computers available will be needed to process and analyze spatial information, particularity at larger scales of integration (e.g. extrapolation by models to regional analysis).

2) prone to utilize vast amounts of storage on computing devices because each operation or overlay develops a new map and often many overlays are required, particularly during project development and during the simulation modeling phase (a new image for each time step in the model). 3) require careful design and management of data and images because of their volume and

complexity. (It may require many hours of computing to make one map.)

4) require costly input and output devices which may tax local sites due to operation and maintenance. (Map scanners can substitute for digitizers; matrix cameras and color laser printers to produce quality output.)

Previous documents (Shugart Report--Franklin Mandate) and the Technology Committee recognize the importance of addressing ecological issues from the temporal and spatial variability perspective and to pursue the development and validation of simulation models, including new classes of spatial analysis.

Technology Development:

New technologies are available or are currently under development which will satisfy some of the concerns addressed above. These include: high-speed computers or supercomputers which are currently remote access/batch systems available via networks. In the near future, microcomputers with parallel processing capability will begin to compete with processing power of remote systems. For example, industry leaders predict that by 1992 desktop processors will run at 25 MIPS and will cost in $25K. Information storage devices are at the threshold of a breakthrough with new developments in read/write optical storage devices which are able to store gigabytes on a cartridge. New developments in software systems are entering the marketplace including new systems for analysis of geostatistics; new developments in GIS systems with emphasis on user interfaces through applications of expert system and artificial intelligence and upgrades of existing systems are planned because of intense competition from new systems. Simulation modeling is being enhanced by modeling tools and much concern and interest is developing to allow an interface between simulation modeling and GIS systems. New input technology such as digital scanners will optimize the tedious component of GIS--map digitizing, and these systems must be seriously considered to increase investigator efficiency. These systems are lessening. Image capture systems are playing and will play an increasing role in spatial analysis and interpretation of relationships and processes. Output devices have improved dramatically in the past few years. High resolution display, matrix camera recorders, color laser printers all have a role in the processing and interpretation of spatial imagery.

Spatial Analysis/GIS:

The LTER network is acquiring the capability to input process information and manipulate spatial components of ecosystems. Integrally, these systems are called Geographic Information Systems (GIS). GIS provides capability for simple map production (soils maps) or permits multiple map overlays so that examination of ecosystem interactions can be made (e. g. display the areas where soil type x co-occurs with nutrient level y and plant species z and calculate the area of co-occurrence). GIS also provide statistical capability (area computation, frequency analysis, cross-tabulation, principle component analysis). in addition, a feature provided by some GIS's include extrapolation from sampled areas (point estimate samples per unit area such as plant biomass samples, estimates of nutrients, microbial population counts, insect trap catch, etc.) to produce maps based on user supplied sample to sample relationships and a radius to search out from each sample. However, little attention has been paid to methods of estimating spatial variability from sample points. Other features in raster-based systems include the ability to input, process, rectify, and manipulate the digital form of remotely sensed images (TM, SPOT, AVHRR, etc.).

Development of GIS is rapidly advancing and new systems are arriving in the marketplace monthly. New systems are incorporating new features such as (1) user interfaces applying expert systems approach; (2) input and output systems to interface with other software systems; (3) incorporation of advanced statistical analysis; (4) incorporation of relational database management systems; and (5) general modeling options. Investigators must examine their spatial analytical requirements and select the most easily usable and flexible system.

A new dimension to GIS has been added by NSF through the selection of three GIS Centers with the primary one located in Santa Barbara with others at Orono, Maine, and Buffalo, New York. These Centers should be encouraged by NSF and solicited to provide assistance to the evolving acquisition of GIS facilities at LTER locations and to assist in the development of new technologies as LTER user needs mature.

Geostatistics:

Whenever samples are taken at specific locations to represent the spatial distribution of the attribute sampled (herbivore damage, N content, nematode number, etc.), it is necessary to statistically analyze these spatially distributed data and to compute the variance as a function of the distance between samples. Determining the relationship between sample points requires quantifying the commonly observed relationship that samples close together will tend to have more similar values than samples far apart. The application of geostatistics to ecological variables is essential since conventional statistics do not adequately address the spatial component and we require extrapolation to the layer spatial dimension from these samples. A variety of software systems provide geostatistical capability including data transformation, univariate statistics, variogram analysis, kriging and contour mapping. There are some very low-cost systems which will provide excellent introductions to GIS-geostatistics.

Spatial Analysis and Modeling: (Interface to GIS)

Prediction is a prime goal of ecosystem analysis and integration and many simulation models have been developed to predict ecosystem function and temporal dynamics. With maturity and utilization of GIS, it is feasible to use the predictive ability of simulation models with the display and overlay capability of the GIS. Application of simulation model-GIS interface is a rapidly developing area. For example, a simulation model based on population count and weather can estimate temporal change in insect numbers and resulting herbivory levels to tree species X. By utilizing weather data from 200 stations in a region, the spatial distribution of herbivory can be made for 200 sites, extrapolated to a grid, and overlaid with a digital image of forest distribution to extract the target tree species/defoliation class. Spatially-oriented biological data must be collected to validate models of this type . Major efforts to utilize and integrate simulation models and GIS should be encouraged and supported by NSF.

Supercomputers:

Supercomputers are a class of computers with particularly fast processing capability. Currently, supercomputers exist as large batch or remote access machines located in special environments to optimize speed of processing. New developments in microcomputer technology (parallel processing) will provide the power of today's remote supercomputer on a desktop. (25 MIPS for $25K by 1992.) The processing of spatial data, particularly large areas of closely-spaced points, may require several hours of conventional computing time to overlay images or produce surfaces from point estimates. Analysis of satellite imagery, particularly high resolution satellite images (SPOT, TM) require huge computing resources and these large image processing tasks should take place on supercomputers. Simulation modeling-spatial prediction estimators require the simulation to be run for each coordinate location, requiring many computing cycles.

A hierarchy of computing environments should be available to investigators as they move between small spatial analysis experiments to larger simulations over large regions. Software will have to be available on supercomputers to provide investigators with the appropriate computing environment to accomplish required tasks. Imagery for LTER sites should be available on supercomputers for large scale processing and modeling across LTER sites. These would include standard base maps, satellite images, and appropriate ecological data.

Lead Site:

Each investigator who has a need for these technologies should have ready access to them as they are only tools to accomplish certain ecological objectives. An open invitation, including adequate training, should be provided to all investigators. Supercomputers, in their current state, need to be centralized and the lead site concept is critical to establish the necessary equipment and expertise. The ability of the LTER sites to function as a network will allow the lead site to provide the necessary computing environment regardless of where information is archived. Appropriate database management systems will be as important as the supercomputer capability.

Implementation Strategy:

Standards for collection and access to digital imagery across LTER sites must be developed immediately and this must include support for the digitization of key base images at all LTER sites. All investigators must gain knowledge and have access to spatial analysis technology including low, mid, and high scale computing power and images. Technology should be acquired to automatically digitize and scan large scale maps. This could be performed by a lead site, initially. Access to GIS on supercomputers including software availability on these systems must be supported for inter-site comparative analyses. New spatial analysis techniques and hardware, as identified through working relationships with new GIS centers in Santa Barbara, Orono, and Buffalo, should be made available for LTER spatial analysis and process modeling. Developments in GIS technology and geostatistics must be regularly reviewed especially new systems which conform to existing data and image formats.

One of the critical needs within the LTER network to foster inter-site comparison is to develop standard rectified imagery accessible to investigators. These images should include: base maps (land use; vegetation; topography; soils), remotely-sensed images (TM, AVHRR, SPOT) at key times during the year (peak growth, pre-growth, post-growth). A lead site should be identified to prepare and archive images for other sites.

All investigators should have access to computing power and software to match requirements of their research programs. A framework of systems philosophy and access to simulation models and spatial analysis systems is key to successful within- and between-site research. Lead sites should be identified to advise others on direction for computing and modeling technology. Facilities are needed to accomplish special simulations, custom digitizing, image scanning, high-quality photography of images for LTER investigators. Lead sites should be identified to address special requirements of LTER investigators. Image analysis, especially of complex landscapes, requires vast computer resources. Access to large-scale supercomputers to perform complex simulations of spatial patterns must be provided to LTER investigators. The computers must have appropriate software and output facilities to provide this capability to users. Optimal use of existing supercomputer facilities must be encouraged by providing investigator training and incentive.

4. COMPARATIVE EXPERIMENTAL TECHNOLOGIES

Research Facilities Needed to Determine Biological Responses to Climate Change

Scientific Rational:

Biological responses to climate change is a topic at the heart of IGBP. As defined here, climate change includes changes in temperature and moisture regimes and in the gaseous composition of the atmosphere. Changes in these abiotic parameters will, in turn, cause changes at many levels of biological organization from molecules to the biosphere, and so there will be opportunities for cooperation among the sub-disciplines of biology, from biochemistry to ecosystem science practices at the global scale. Initially the changes may be subtle, for example, changes in plant tissue chemistry and structure. Next, there may be changes in ecosystem processes, including production and decay. Finally, there may be changes in populations and community structure.

Ecosystem ecologists have already realized that the responses of the producers and decomposers are likely to be asynchronous, making whole-ecosystem responses to climate change difficult to predict. Therefore, whole-ecosystem manipulations will be required in our studies of biological response to climate change. We recommend that facilities be established at several LTER sites to carry out climate manipulations at the whole ecosystem scale.

A variety of structural and functional parameters would be measured at each of these facilities. Structural parameters to be measured would include species composition and biomass. Functional parameters to be measured would include net fluxes of carbon dioxide, carbon monoxide, methane, some non-methane hydrocarbons such as isoprene, oxides of nitrogen, and organic sulfur compounds. Nutrient leaching below the rooting zone would also be monitored. All measurements would have to be non-invasive.

Overview of Technologies Available:

Scientists have relatively little experience with whole-ecosystem manipulations of the type we are advocating. The most relevant experience comes from DOE-sponsored research on the direct effects of elevated carbon dioxide on ecosystems. Three basic approaches have been take to creating altered environmental conditions; open top chambers, free air circulation experiments (FACE), and closed systems. Both the open top chambers and FACE appear to be suitable for manipulating carbon dioxide levels, but for obvious reasons neither appears appropriate for manipulating temperature and moisture in conjunction with carbon dioxide manipulations. In addition, neither open top chambers nor FACE is appropriate for measuring net gas fluxes unless additional technologies are used (see later sections).

The combined manipulation of temperature, moisture and gaseous composition of the atmosphere appears, then, to require closed systems. To our knowledge, only one whole-ecosystem experiment of this type has been conducted and it was done by Dr. Walter Oechel and his colleagues in the tundra of Alaska. They enclosed small areas (slightly > 1 m^2, 0.5 m high) and controlled carbon dioxide concentration and temperature for several growing seasons. Similar experiments on larger stature ecosystems such as forest have not been attempted.

Number of Facilities Need in the LTER Network:

Since these facilities are going to be costly to establish and operate, it is clear that they can beestablished at only a few sites in the LTER network. A committee should be formed to identify the sites, minimally 4, that represent important terrestrial habitats likely to be affected by climate change. The experiments conducted in these facilities should run for at least a decade.

Cost to Implement:

At the present time we do not have carefully worked out costs estimates for the building and operation of the proposed facilities. Therefore, the TC recommends that an engineering study be funded to develop accurate cost estimates. Very preliminary cost estimates for the construction and operation of closed systems in small stature (tundras and grasslands) and large stature (small temperate and boreal forests) ecosystems were made at a recent SCOPE meeting. These estimates are outlined as:

System Type	Dimension	Construction Cost	OperationCostper12 chambers/yr
small	5m x 5m x 2.5m	$50,000	$250,000
large	10m x 20m x 10	$250,000	$350,000

These estimates are based on rough calculations made by Dr. Oechel. Each chamber would be built of aluminum framing and IR transmitting walls. Mechanical facilities would be shared among chambers and there would be a backup of mechanical facilities. Based on these rough estimates, a site that was developed with a set of twelve small chambers would cost $600,000 to construct and $2,500,000 to operate for a decade. Likewise, a site that was developed with twelve large chambers would cost $3,000,000 to construct and; $3,500,000 to operate for a decade. The total cost of constructing and operating a set of chambers at each of four LTER sites for a decade would be between $19,000,000 and $20,000,000.

The above categories identify a combination of approaches, experiments, and measurements prioritized according to selected criteria. There are a number of advanced technologies that also were identified as important to the research goals of the network. in many cases these technologies would be used with some or all of the above topics. Thus, they are discussed here without priority ranking.

ADDITIONAL TECHNOLOGIES TO COMPLIMENT RESEARCH THEMES

STABLE ISOTOPE TECHNOLOGIES FOR LTER

Scientific Rationale:

A common objective of LTER sites is to understand spatial and temporal patterns of production and nutrient cycling, and related processes. This is a complex task requiring measurements of carbon and element flux at varying scales (both space and time). Frequently knowledge is required of the relative importance of multiple sources to some process. For example, what fraction of a plant's nitrogen uptake is derived from the soil pool versus biological fixation of atmospheric N2, or what is the relative contribution of marine versus terrestrial carbon to animals in estuarine environments? Questions such as these may be investigated using recently developed stable isotope ratio technologies. The elements H, C, O, N, and S each have an abundant and a rare stable isotope. Minor variations in the ratio of the rare (the heavier) to the abundant isotope (e.g., D/H, 13C/12C, 180/160, 15N/14N, 34S/32S) occur among biological materials, soils (sediments), and atmospheric gases. These differences in isotopic composition result from isotopic fractionation during biological and physical reactions.

Recent advances in the design of stable isotope mass spectrometers have made it possible to accurately determine small differences in isotope ratios between samples. This has led to the development of many applications of stable isotope measurements to ecosystem studies. The uses of stable isotope ratios in ecological studies have recently been review by Rundel et al. (1989) and Peterson and Fry (1987). Examples of applications of these methods that are currently being used by LTER or have potential for future use include:

D/H: water sources for plants, climate reconstruction

13C/12C: plant water use efficiency, plant photosynthetic pathway, C sources in animal diets, soil organic matter cycling, paleoclimate reconstruction from carbonates, methane source identification.

180/160: paleoclimate reconstruction, plant water budgets

15N/14N: symbiotic nitrogen fixation, nitrogen cycling, atmospheric sources

345/325: anthropogenic inputs of S to ecosystems, S cycling especially in sediments.

Advantages/Disadvantages:

The advantages of stable isotope measurements are that they provide information about source-sink relationships (that is they serve as tracers) and they provide time-integrated information about biogeochemical processes. The relative contribution of multiple sources to a process can be determined from isotope ratios. In addition information about difficult to study belowground processes (such as nitrogen fixation, water uptake by surface versus deep roots) may be obtained from the analysis of easily collected aboveground plant tissues. In addition, there are reasons to expect that stable isotope ratios might be sensitive indicators of directional changes in important ecosystem processes (e.g., changes in N cycling, plant water use efficiency) that may result from global climate change.

Stable isotope ratio measurements provide useful information only if the sources under study have significantly different ratios and only if these ratios are not altered by isotopic fractionation processes beyond our abilities to correct for these effects. Our understanding of the potential of stable isotopes for ecosystems analysis is limited by the relatively few number of studies to date and the lack of any information for many important ecosystem types.

There has been substantial improvement in the design of dual and triple collecting stable isotope mass spectrometers over the past 5-10 years. New models with improved vacuum systems, more automated operation, and with sophisticated data acquisition and operating control systems are now available for the analysis of H, C, N, 0, and S isotopes. The principal disadvantages of this instrumentation are the very high cost of stable isotope ratio mass spectrometers (up to $250,000 or more) and the involved sample preparation procedures that are often required. These problems have limited access of this technology to a few groups or centers that have made stable isotopes a major focus of their research. Investigators with occasional or limited isotope data needs have found relative poor access to affordable isotope analyses.

LTER Site Approach:

The attendance at recent workshops and conferences on the application of stable isotopes to ecological studies indicates a growing interest in this field. It is anticipated that the demand for isotope analyses from LTER sites will increase steadily. The high cost to obtain, operate, and maintain mass spectrometers, and the current limited scientific expertise in ecosystem isotope studies, argues for the designation and development of a few lead LTER sites to meet the isotope needs of the entire LTER network. Many mass spectrometers are "set up" to analyze a single element and laboratories may have expertise in only one or two isotopes. Thus, several laboratories of facilities will probably be required to meet LTER needs.

Implementation:

A stable isotope initiative is in progress for LTER under the coordination of Brian Fry (Ecosystems Center, Woods Hole). This initiative will more clearly define the magnitude and scope of LTER interest in stable isotopes. A plan to increase utilization of isotope technologies by LTER should consider:

1. An inventory should be made of existing mass spectrometers within the LTER network and individuals with analytical and applications expertise should be identified. The survey should provide data on the types of mass spectrometers available, sample preparation systems in use, the potential for making isotope determinations for other LTER sites, and anticipated equipment modifications or upgrades that

are required to maintain state-of-the-art.

2. Identify "Isotope Facilities" to serve LTER and upgrade and/or augment existing facilities where needed. The emphasis should be on increasing the capacity of these facilities to serve the LTER network through addition of more automated sample preparation procedures. Technologies for in-line sample preparation and stable isotope ratio determination are available and this technology is expended to improve. Older instruments can be made more efficient by replacing older electronics and interfacing the mass spectrometer with computers for more automated and consistent operation.

3. Explore possible agreements with mass spectrometer facilities funded through DOE, USGS, NCAR, etc. to provide needed analyses and expertise.

The cost to implement a stable isotope program for LTER will depend on the existing facilities andtheir condition. A new instrument and the associated sample preparation equipment can exceed $300,000. The cost to upgrade a 10 year old mass spectrometer might run from $40,000-80,000.

SUBSURFACE TECHNOLOGIES

Minirhizotron

Scientific Rationale:

Many of the critical processes and interactions affecting ecosystem production and nutrient cycling occur in the subsurface (soil, sediments, water column) environment. Understanding the subsurface component of ecosystems is one of the most difficult tasks facing LTER. Most LTER sites have a need to understand root growth and production. Root production may be a large fraction of the carbon and nutrient flux in terrestrial ecosystems. Roots influence the distribution and activity of soil biota and may affect the flux of trace gases from soil.

There are many traditional methods for the study of roots. These methods usually require removal of soil (coring) and thus, are destructive and require large amounts of labor. Related approaches include use of root in-growth bags and large rhizotrons (glass plates) for root observation. More recently the use of root periscopes has gained attention to allow direct observation of root activities in time and space. This technology usually referred to as the "minirhizotron" involves lowering a periscope or video camera system into a clear observation tube. Once the root observation tube has been installed root growth, root orientation, and changes in root condition can be monitored non-destructively. A. Smucker (Michigan State University) has identified 35 root and soil parameters that may be evaluated using minirhizotrons.

Advantages/Disadvantages:

An excellent summary of the use of minirhizotrons and their limitations is found in Taylor (1987). The state-of-the-art minirhizotron system is based on a miniature color video camera that can be lowered into the root observation tube. The Circon Corp. (Santa Barbara, CA) has developed such a camera for minirhizotron use and this system is the most widely used at present. Other cameras suitable for this application are either available or are in the design or testing stages by a few other manufactures. Improvements to rhizotron cameras that should further enhance their application to root and rhizosphere study are higher resolution, remote focusing, and more compact camera systems.

An important advantage of minirhizotron video-camera systems is that root profile images ran be recorded on video tape for later analysis (and for storage), often by image analysis techniques. The camera system is relatively easy to operate and use in the field. There are also statistical advantages to the minirhizotron over more traditional glass plate methods since relatively large numbers of root observation tubes may be installed at a site providing greater replication. It is anticipated that minirhizotron approaches should be more cost effective than traditional soil coring and root separation techniques for many sets of conditions.

Limitations of the method are common to all techniques where close contact between some surface or a probe and the soil are required. In rocky, shallow soils it may not possible to insert observation tubes and the technique works best where moderate to high root densities occur. The technique appears to give poor results for the upper 10 cm of soil (light and/or temperature effects of the observation tube), which is some ecosystems is the zone of the important root dynamics. The cost of the color video camera is between $15,000 and $20,000. The full potential of the minirhizotron will require use of image analysis approaches to speed processing of the video images of roots. A. Smucker at Michigan State University is developing an image analysis protocol for minirhizotron data.

LTER Site Approach:

The minirhizotron technology should be available to individual sites that have a strong interest in root function and production. Although operation of the camera system per se is not difficult, considerable experience with roots and root observation is desirable to obtain accurate results. Sites could quickly become proficient in obtaining root images. Progress in the design of minirhizotron studies, and especially in image analysis procedures might be focused at a few sites. These sites could provide training in use of the system and the image analysis needed to fully utilize the kinds of information encoded on the video tape.

Implementation:

A survey and/or workshop of LTER sites currently using or hoping to use minirhizotron technologies is needed to assess current expertise and experiences with this method. The cost of the camera system is not prohibitive if this approach can substitute for more labor intensive destructive methods. Approximately $20,000/site would be needed for set up. Image analysis software and related computer hardware would be extra costs and are difficult to predict. Individual sites should be aided in obtaining this technology. The full potential for this method will require testing at a diversity of LTER sites. An intermediate approach would be to fund a few sites representing different dominant plant growth forms and sets of soil conditions for a field evaluation of the technology before recommending use by other LTER sites.

Other Applications:

There are a suite of technologies designed to provide a three-dimensional view of subsurface systems. These approaches involve generating signals that can penetrate the media (soil, water). The signal is reflected or altered through interaction with roots, soil layers of different bulk density or organic matter content, and the altered signal is recorded. Sophisticated computer assisted analysis is required to obtain the three-dimensional information encoded in the signal. These technologies are generally at a stage of development that precludes routine use or use in the field (with the exception of ground penetrating radar). LTER should monitor the development of these technologies as they may have potential for subsurface imaging. Promising technologies and their applications are:

Ground penetrating radar: Systems are available commercially that can penetrate soil to a depth of several meters. GPR has been used to assist in soil mapping by determining the depth to certain soil horizons, the depth of soil organic layers in peats, etc. This technology may be used to assess subsurface heterogeneity in soil structure (Schellentrager et al. 1988). It may be able to differentiate roots under some soil conditions.

Computer-assisted tomographic (CAT) scanning: This technology was developed for medical uses to provide two and three dimensional images of tissues and organs. It is based on x-ray transmission radiography and mathematical reconstruction theory. Recently it has been used to examine bulk density of soils, spatial changes in soil water content with time, and for oil-related research (Jenssen and Heyerdahl 1988). A mini-scanner has been developed. Smaller less expensive units are required before this technology will become affordable and accessible. At present relatively small samples (e.g., soil cores) must be brought to CAT facilities typically located at a large medical centers. Nuclear magnetic resonance (NMR) imaging: Proton NMR and NMR imaging comprise a medical technology that uses static and radio frequency magnetic fields to acquire maps of the mobile water distribution in biological materials. This technology has recently been used to study root distribution and the movement of water through plants (Rogers and Bottomley 1987).

Advantages Disadvantages:

These methods have the advantage of being non-destructive and provide information on the three dimensional structure of subsurface features such as roots. The large disadvantage is the inability to move this technology to the field at the present, the great expense of the instrumentation, and the poor access to non-medical users.

LTER Site Approach:

No intensive LTER action is needed in regard to these and related technologies. The LTER Technology Committee or some counterpart should routinely keep track of advances in these fields for potential field scale applications.

Another technique that warrants watching is acoustic tomography being developed at Los Alamos. This involves placing a circle of core holes around an area (i.e., several m dia.) and using acoustic techniques to interpret the soil volume within the circle. This technique is still in the development stage.

TECHNOLOGIES FOR INTERMEDIATE SCALES OF RESOLUTION

Scientific Rationale:

Traditional ecological studies have been small scale relying on techniques such as simulation modeling, statistical approaches, and at times simple addition or multiplication to extrapolate results to larger areas and scales. The problems associated with such extrapolations as well as scale dependent results of individual studies are cited often in current literature.

In addressing goals such as global change, it is becoming clear that we cannot hope to understand fully or predict meaningfully the course of any single long-term environmental change without understanding a LTER site as a whole, the region of the LTER site is to represent as a whole, the North American content as a whole and even the earth system as an integrated whole. Contemporary advances in technology, such as the ability to observe the earth from space and the rapidly accelerating capabilities for data handling, numerical modeling, and telecommunications, make large scale change studies feasible at this time. For example, satellite-borne sensors, world wide communications systems and supercomputers allow sensing of the earth system as an integrated whole. A major challenge is to relate such analyses to the underlying processes that may operate on much smaller scales, i.e. what is the biotic-abiotic cause of the spectral signal recorded by the aircraft/satellite sensor. Observations of the pattern of events and changes is possible; however, predicting change at large scales requires an understanding of the underlying processes, or at the very least, detecting the relationships between the patterns observed and the processes we can model. To calibrate and validate models, it is essential to be able to measure environmental parameters at a variety of scales in order to examine the validity of the scaling assumptions in the model.

Many processes, i.e. primary productivity, mineral cycling, evapotranspiration, vary continuously both spatially and temporally. The appropriate scale is for studying these processes rarely known. There is a dearth of results and techniques for measuring process phenomena at scales intermediate between point measurements of biophysical ecology and meteorology and the large scales now possible with remote sensing from satellites. Studies must be performed over a range of scales to determine when it is possible to extrapolate from short, spatially restricted observations to long-term large spatial scale changes. They also are necessary to determine rules of aggregation or extrapolation used in GIS techniques.

The research goal of comparative studies of ecological phenomena and theory has similar constraints. The phenomena undoubtedly are related to scale-specific features of each environment/habitat. Understanding the scale-dependency of results of any phenomena is crucial in comparative studies.

Overview of Technologies Available:

The majority of technologies we will address operate in the 1 m to 1000m spatial range. Some provide integrated values over the entire range, some work over different portions of the range. An additional important component of many of these technologies is that they are noninvasive and nondestructive. These are important features of methods necessary for long term studies. The same area can be measured with reduced risk of change caused by the study itself.

The types of measurements are classified into;

a. structural features - pattern in substrates, species, community, landscape and change through time

b. process phenomena - biogeochemical dynamics sources, sinks, fluxes, and interactions of mobile constituents (water, gases, nutrients)

Structural features - pattern:

Structural features can be sensed over a wide range of the electromagnetic spectrum (UV to microwave). Sensors operating at various wavelengths detect different pattern, and different structural characteristics. Typically, a given sensor will operate at different scales of resolution by varying the distance (height) and field of view (FOV). Thus, the same instrument can be used close (small scale resolution) to distant (large scale resolution) from the object. Data from such variations in scale can allow extrapolations from ground or point measurements to scales of resolution used by satellite sensors. Repeated measurements over time can allow change detection and inferences about the dynamics of processes. Examples are changes in chlorophyll concentrations (i.e. carbon fixation) and changes in soil moisture (i.e. evapotranspiration). Sensors currently available include:

-continuous spectrum radiometers

-fixed band radiometers

-standard photographic systems (visible to IR film)

-still video camera systems (analog storage of image on diskette)

-microwave (radar).

The platforms for these sensors are fundamental in varying the scale of measurement. Essentially they vary the height of the sensor and the FOV. Standard platforms include:

-aircraft (including drones)

-balloons

-towers or booms

-handheld.

A fundamental part of a number of these systems is the image digitization and processing capability. Software systems, some general, some instrument specific, are commercially available. Data generation by these systems can be extensive (e.g. .6 Mbyte per image for a still video camera) and good data management capabilities are essential.

Process Phenomena:

In addition to detecting some processes from aboveground sensors, a number of technologies are becoming available that operate at ground level over varying spatial scales. Many of these are in a prototype or research stage but continued success should allow increased numbers and availability, certainly in 5 years time.

LIDAR (Light Detection and Ranging):

Evapotranspiration - The Los Alamos National Laboratory LIDAR system will provide a 3-dimensional view of water vapor concentration, eddies, and fluxes in the near-ground atmosphere. This allows analysis of spatial variability at a number of scales. It also is a methodology whereby the temporal variability of fluxes can be studied over various time scales. Data are water concentrations per 1.5 m interval out to 1 km or better. A typical 1/2 minute LIDAR scan provides 6 million independent measurements of water concentration inside a cubic km volume. These data are acquired in a spherical coordinate system and can be rearranged to provide maps of the water content on 10 to 20 vertically stacked horizontal planes covering approximately 150 ha each. The LIDAR system also allows multiplescale meteorological measurements. The techniques result in identification of eddy cell locations, dimensions, frequencies of occurrence and movement in the near-ground atmosphere.

Aerosols - The University of Wisconsin LIDAR system detects aerosols rather than water. The system approach is similar to the Los Alamos LIDAR except for the laser wavelength and the same multiple-scale meteorological measurements are possible. Eventually, many gas species will be measurable remotely with the use of tunabie lasers and the Differential Absorption Lidar (DlAL) technique. Laser systems are currently used for remote measurements of the vertical distributions of atmospheric pressure and temperature and the atmospheric distributions of gases such as ozone. New innovations in laser technology are being directed towards the measurement of any gas having strong absorption characteristics; lasers for measurement of carbon monoxide, methane, ammonia, sulfur dioxide, nitric oxide, and nitrogen dioxide are presently being tested for use from aircraft platforms.

The sophistication and expense of these systems will require a lead-site concept even after the technology is verified.

FTIR (Fourier Transform InfraRed spectroscopy):

Long-path infrared spectroscopy can measure numerous atmospheric gases, simultaneously, at ambient levels because these gases can be detected by their infrared absorption patterns. The long path capabilities provide a valuable approach toward studies of gaseous emissions and biospheric/atmospheric interactions in natural environments. Natural environments are heterogeneous and complex and larger scale measurements that integrate the variability both spatially and temporally will increase our ability to quantify these phenomena. The ability of the technology to distinguish isotopic forms of various gases potentially provides a powerful tool with which to trace the source and cycling pathways of many gaseous compounds containing C, N, S, and O that originate from divergent sources. A major challenge will be to develop methods to convert concentration measurements over larger spatial scales to accurate estimates of average flux. These techniques are being investigated currently; however, until validation studies are performed, FTIR remains in a developmental stage. The LIDAR technology described above represents the best-developed method for relating concentration data to fluxes at this time. The current stage of FTIR research identifies this technology as very promising but at a prototype nature. A lead-site concept is most appropriate at this time; however, the instrumentation has the capability of being deployed at all sites and used for continuous measurements as well as with specific experiments. Additional research will involve redesigning the instrument to be more efficient, smaller, more mobile, and having increased data management capabilities.

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