(496)

Climate Studies in the Long-Term Ecological Program

David Greenland

ABSTRACT: Since the inception of the LTER Program in 1980, climate has been studied at individual LTER sites and an LTER Climate Committee has been responsible for inter-site activities. At individual sites, climate studies support ecological research, emphasize intra-site heterogeneity, and often relate to other national monitoring and research programs. In inter-site work, the Climate Committee has produced protocols for meteorological observations, described and compared climates of the first 11 sites, and raised important issues regarding climate variability and ecosystem response.

The Long-Term Ecological Research (LTER) Program, sponsored by the National Science Foundation, contains 18 sites in a variety of ecosystems. Climate is studied within and between individual sites. This brief review gives some examples of the range of work performed at individual sites and then describes some inter-site activities.

Climate Studies at Individual Sites

Climate is studied at each of the 18 sites. Although highly variable, the studies have two common goals.

- They seek to support the research — especially long-term research — of ecologists at the site.
- They are usually oriented to one of the five core research areas of the LTER program, particularly the areas of primary productivity, organic and inorganic fluxes, and disturbance.

Availability of a long-term climatic record at most LTER sites makes it possible to identify directional changes and to place a perspective on the importance of individual climatic events. Analysis of the Niwot Ridge climate record, for example, suggests a move to cooler, wetter conditions (Greenland 1989). This move correlates with shifts in plant community composition, reduced soil pH, and modified controls on nitrogen limitation to vegetation. The analysis also suggests some cyclicity in annual precipitation values and identifies years of high or low precipitation, which might be categorized as disturbance to the ecosystem. Similarly, Molles and Dahm (1990), working at the Sevilleta LTER site in New Mexico, have noted important effects of El Niño and La Niña phenomena on stream ecology. At some LTER sites massive climatic disturbance has been documented, as in the case of the huge impact of Hurricane Hugo on the North Inlet Marsh site in South Carolina and the tropical rain forest site at Luquillo Experimental Forest in Puerto Rico.

In: K.T. Redmond and V.L. Tharp, Editors. 1993. Proceedings of the Ninth Annual Pacific Climate (PACLIM) Workshop. April 21-24, 1992. California Department of Water Resources, Interagency Ecological Studies Program, Technical Report 34.

Within-site climate studies often point up small-scale variability. Alpine tundra, which may appear quite homogeneous, has been shown to have a variety of micro climates when values of the surface heat energy exchanges at different vegetation surfaces are measured (Greenland 1991). Although most sites are generally representative of a particular biome, some sites are on the border of more than one. The Sevilleta site, for example, includes Great Plains grassland, Great Basin shrub-steppe, Chihuahuan Desert, interior chaparral, and montane coniferous forest biomes.

Usually each LTER site is also networked into one or more regional or national climate-related program. Many sites, for example, belong to the National Atmospheric Deposition Network. The Konza tall grass prairie in Kansas was also the site of the first ISLSCP field experiment (FIFE) of the International Satellite Land Surface Climatology Program. The Niwot site is also a long-term monitoring station for carbon dioxide and other gasses in the NOAA Climate Modeling and Diagnostics Laboratory monitoring program.

Inter-Site Activities

The LTER Climate Committee initiates inter-site activities. The committee has established standards for meteorological measurements at LTER sites (Swift and Ragsdale 1985; Greenland 1986a, 1986b) and has described and compared climates of the first 11 LTER sites (Greenland 1987). The committee has also examined the topic of climate variability and ecosystem response (Greenland and Swift 1990, 1991).

In establishing standards for LTER site meteorological measurements, Swift and Ragsdale (1985) developed the approach of a hierarchy of measurement sophistication. At the entry level, sites are required to record only daily maximum and minimum air temperatures and precipitation values. At the three higher levels, sites gain increasing complexity and inclusivity in the variables observed and their manner of observation. At least one location within most LTER sites now use electronic data sensing and logging systems. The hierarchical approach proved popular since it allowed greater budgetary flexibility at individual sites.

The network is by no means optimal for giving geographic coverage of the United States. Consequently, approaches other than geographic have to be employed in comparing climates of the individual sites. The committee has presented diagrams of "climate space" into which the LTER sites are placed (Greenland 1987). Such diagrams are two dimensional and have axes indicating simple variables, such as annual mean temperature and precipitation, or derived parameters, such as Thornthwaite's modified moisture index and potential evapotranspiration. These diagrams and accompanying tables of the sites ranked by various climatic parameter values are useful in designing ecological experiments when abiotic gradients across the LTER Network need to be selected.

The Climate Committee also renders services to the LTER community such as providing climate information for publications (*eg*, Van Cleve and Martin 1991) and an electronic newsletter/bulletin board, CED (Climate/Ecosystem Dynamics), produced by Dr. Bruce Hayden at the Virginia Coast Reserve LTER site.

Some of the most useful ideas from the LTER Climate Committee arose from the workshop "Climate Variability and Ecosystem Response". Most of the following material is drawn from workshop results (Greenland and Swift 1990, 1991). As a committee we identified four issues to be considered in future investigations:

- Need to clarify terms and definitions used in discussing climate variability.
- Importance of recognizing the various time and space scales of climate variability and ecosystem response.
- Need to expand data beyond dependence on traditional summaries of temperature and precipitation.
- Value of insights from examining similarities and dissimilarities among climate episodes and ecosystem responses across LTER sites.

Some of these issues are briefly addressed below.

Scale is an important consideration because it determines what kinds of questions can be asked about the operation of an ecosystem. Researchers must relate scales on which climate systems operate to scales on which the biotic parts of the ecosystems operate. The definition of climate, as perceived by an individual component of the ecosystem, is directly related to scale. A soil micro-organism might regard an individual rainstorm as a significant climatic event, whereas a tree at the Andrews site in Oregon would be acclimated to a climate range far exceeding that found in any 30-year climatic normal. Each ecosystem responder defines its own climate scale. LTER sites should be equipped with the tools to put events such as droughts and storms into perspective. An example of such tools is the Z-T methodology applied at the Coweeta site (Swift *et al* 1990).

Current climatic data impose several time- and space-scale limitations. The time limitation is that the length of the reliable observed climatic record in most parts of the United States is on the order of only a hundred years or less. A scale limitation is that most modeling studies based on current General Circulation Models (GCMs) employed to investigate effects of increase in greenhouse gasses are on a scale so large that a state the size of Colorado might contain only one grid point.

Thus, we concluded that to understand climate variability and ecosystem response demands, we must pay particular attention to space and time scales. We must beware of arbitrarily imposed, human-derived scales and concentrate on those scales that emerge from the functioning of the ecosystem and climate systems. Research should specifically identify those functions and processes of the ecosystem that cannot keep up with potential rates of abiotic change, such as postulated global warming rates.

We recognized a continuing need for consistency in obtaining and handling data across the LTER network. Of great value would be new indices that are not directly dependent on monthly and annual mean temperature and precipitation values. Dr. Anthony Federer of the Hubbard Brook Experimental Forest, New Hampshire, LTER site believes a water stress variable would be important in this context. Such a variable might be accumulated deviation of daily precipitation (or temperature) or more complicated ones involving soil water budget factors. One such indirect index, the date of lake freezing, was demonstrated for the Northern Lakes LTER site (Robertson 1990). However, this is specific for the LTER site and ecosystem it represents and cannot apply at all to some other sites.

An index that seemed to have wide application for inter-site comparisons emanated from air mass climatology. Wendland and Bryson (1981) used streamline analysis to map airstream regions. The regions are defined by the boundaries between airstreams from different global source areas. Almost every LTER site has periods during the year when there is a shift between being in the region of one airstream and being under the influence of air from another. The number of months duration in different airstream regions provides an index for comparing LTER sites. Wendland has examined air mass frequency data for all LTER sites. The duration of each air mass from various source regions is a representation of the climate for a particular period. In another time period, the air mass frequencies might change, especially at sites near the confluences of airstreams. Thus, this data form may provide evidence of shifts from one climatic episode to another. There is a certain amount of subjectivity in some forms of air mass analysis, and the subject is still being refined (Schwarz 1985,1988). Nevertheless, the approach has considerable potential for identifying climate variability for some biomes. We recommended that sites, singly and as a network, investigate new and nonstandard climatic indices to supplement information obtained from standard climatic observations and summaries.

A benefit of having LTER sites in different biomes is the possibility of broad-scale comparisons, not often available to ecologists, which should give valuable insight into ecosystem function and processes. This was demonstrated during the workshop when similarities and dissimilarities between sites were examined.

Many sites have not yet identified clear or obvious ecosystem responses to slow climate trends or even to events of mid-scale severity. But most sites have experienced major responses to a severe weather event. The Hubbard Brook ecosystem, for example, was not markedly disturbed by the droughts of the 1960s but still shows the effect of a single hurricane in 1938. Tree blowdown has been a repeated catastrophic wind-related event at several LTER sites, and hurricane damage has significantly altered both the North Inlet and Luquillo ecosystems (Biotropica 1991). Many ecological responses are due to secondary effects of atmospheric events, such as flooding or landslides. For example, the redistribution of sediment by an intense rainstorm on the otherwise dry Jornada site has marked consequences on the biota either by burying them or by providing new micro habitats.

Several sites reported possible time coincidence for discontinuities in the values of climate variables. The years of changing climatic episodes suggested by shifts in freezing dates of Lake Mendota, Wisconsin, near the Northern Lakes LTER site, in 1880, 1940, and possibly 1980 were also noted as times of change at some other sites. LTER sites may benefit from examining their own records for common break points in datasets. Data at most sites, as well demonstrated by the Central Plains Experimental Range (Kittel 1990), follow hemispheric or at least regional trends in temperature and precipitation. This augurs well for the extrapolation of results from the LTER network to larger areas. Yet unique or isolated sites, such as Niwot Ridge, will not necessarily display the same spatial and temporal trends as adjacent dissimilar areas.

Several fertile areas for further research can capitalize on the similarities and dissimilarities of climate variability and ecosystem response across LTER sites. These include investigation of:

- The importance of catastrophic events in relation to slower trends and cycles.
- The time coincidence of certain major climatic discontinuities that appear to exist at several sites and the effects on ecosystems as they shift from one episode to another.
- The relationship of climate to phenological studies across the LTER network.

Conclusion

The LTER program provides a useful base for climate studies, both within individual sites and across the LTER network. By looking at climate problems from an ecological viewpoint, insights may be gained and many questions may emerge. The highly disparate nature of LTER sites allows us to search for indices, like air mass frequency, that go beyond information restrained to local observations of temperature and precipitation. Climate studies in the LTER network are leading to a broader search for new concepts and techniques in ecosystem science as a whole.

Acknowledgment

The Long-Term Ecological Research Program is sponsored by the National Science Foundation (Long-Term Projects in Environmental Biology) through grants to individual sites and to an LTER Coordinating Committee.

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CL/PACLIM-IATR/92-34

PROCEEDINGS OF THE NINTH ANNUAL PACIFIC CLIMATE (PACLIM) WORKSHOP

Asilomar, California—April 21-24, 1992

Edited by
Kelly T. Redmond and Vera L. Tharp

Technical Report 34
of the
Interagency Ecological Studies Program
for the
Sacramento-San Joaquin Estuary

March 1993